# Expert System for Diagnosis of Motor Failures in Electronic Injection Vehicles

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***Abstract*—**

**Today, cars are an indispensable element in the society, as well as the vehicle diagnosis of minor and serious mechanical failures. This process is carried out through two methods: (i) manually, inspecting possible common causes; and (ii) automatically, using a failure identification scanner. In both cases the assistance of a car expert is required. However, how could a common user briefly diagnose vehicle failures? The objective of this project has been to build an expert system module for vehicular diagnosis to help the common user, identifying automotive failures and the severity of the vehicle damage. It also helps to prevent major damages and possible accidents, as well as to achieve a technical and effective communication when the situation is being explained to the mechanical assistance which can be even by telephone. The module design was composed by four phases: (i) do background research about failure diagnosis, (ii) production rules; (iii) inference engine; and (iv) user interface. The results show that the expert system module is 71,43% effective, so that it helps the common user to identify electronic engine failures without the assistance of a professional in the area.**

***Keywords*—*Expert System, diagnosis of mechanical failures, artificial intelligence***

## I. Introduction

Today, cars have become a key and indispensable element of society whose main function is to provide mobility, comfort and safety to the driver. However, these advantages can sometimes be affected by failures in the car, failures that usually occur due to normal wear and tear on the vehicle.

Some failures are easy to identify while others are not. The first ones are considered as minor and do not present problems in the engine, such as: failures on the horn, lights, windshield washer, air conditioning, entertainment, and so on. On the other hand, for the second or serious failures, a diagnosis must be made through: (i) a manual inspection of possible common causes, or (ii) a scanner to identify error codes of the car. In both cases the assistance of a specialist is required to identify the mechanical failure and solve the problem with or without the replacement of parts.

However, how could a non-expert user in mechanics briefly diagnose moderate / severe vehicle failures, avoiding major damages or possible accidents for the use of the vehicle in non-stable conditions?

The present project proposes the design of an expert system module for the vehicular diagnosis of moderate / severe failures in engines with electronic injection system, because it is based on a set of actuators and sensors that register data quantities through signals of electrical nature, which are concentrated in the electronic control unit (ECU) and can be used for the timely identification of failures by an expert system.

The early vehicular diagnosis helps the common user to identify failures and the seriousness of the problem; in order to: (i) avoid and prevent major damages and possible accidents; (ii) achieve reliable communication with the expert when explaining better the damage of the vehicle, minimizing the time and cost in the repair or arrangement. The main contribution of this research is that the solution is designed to be used in an agile and friendly way by the most ordinary users who are not experts in the automotive area.

Here are some concepts that will be useful in the rest of the paper.

## II. Theoretical Fundament

### *A. Expert System*

Expert systems (ES) are computer systems (made up of hardware and software) that contain and simulate the behavior of human experts in an area of specialization [1], being able to process, memorize and restructure information based on new data, it is about learn and reason unknown knowledge on the progress, communicate with people or other expert systems, make appropriate decisions or skip rules when it is identified that the solutions are not applicable to the specific case, and explain why such decisions have been made [2].

An ES uses human knowledge stored in a database related to the problem (discipline) to be solved [3]; that can be used by non-expert users to improve their problem-solving skills, or by the experts themselves as assistants in their activities [4].

The ES are considered as part of artificial intelligence (AI) [5], which could be based on probabilities or on production rules. In the ES based on rules; the inference engine is the fundamental one, which is in charge of executing the algorithms, rules from the facts, historical data to find a solution in an autonomous way [6].

An ES consists of four interconnected parts: (i) fact base that represents the current knowledge of the system about a specific

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case; (ii) the base of production rules, representing the knowledge of the expert; (iii) the inference engine, which obtains the conclusions (response) applying the logic of the rules; and (iv) the user interface that shows the results obtained [7].

The inference engine obtains the conclusions based on the methods of (i) forward chaining, (ii) backward chaining and (iii) production rules.

The base of rules, uses the structure if - then [4] [7]; which can also be constructed by using decision trees, that can provide a schematic graphic vision of the succession rules, it means, it lets see actions that must be taken and the order how the decision will be made. This is known as interpretability and it is necessary in certain application contexts.

In the study of the ES, several applications were also found in the area of mechanics that have been helpful for the development of the document:

The research presented by Al-Taani [8], the ES, used 150 rules for the identification of 100 types of failures, which proposes a process of 4 sequential phases from ignition to vehicle start-up.

The work presented by [9], makes use of the mathematical differential equations in the form of Dynamic Control System in the detection and diagnosis of automobile brake failures.

ACDFA, (automated car failure diagnosis assistance) is an inference engine based on agents for the ES of car failures diagnosis, which can be embedded or independent. The tests were performed by 15 users, the limitation is that the knowledge base adapts to a specific type of car and user, so users need to have prior knowledge about their cars [10].

The ES presented by [11] for the diagnosis of faults in the vehicle's thermostat using data mining and parameterized entropies of the data received from the ECU.

### *B. The Car and the Electric Control Unit:*

In recent years, vehicular automation has modified the mobile and external parts of the engine by adding various sensors, such as: position, pulse perception, odors, among others; this set of sensors records data through electrical signals that the electronic injection system uses in order to collect information that will be shared to the control unit, where it is processed immediately to dose the exact amount of fuel and air that will enter to the admission system and it will put the vehicle into operation [12].

These improvements contribute directly to the efficient performance of the vehicle's engine and consequently contribute to the save of wear and tear of parts and pieces, thus initiating a new era of vehicle diagnosis.

Modern cars have between 60 to 70 sensors in some cases, depending on the model and brand of the vehicle. These sensors, also called probe or transmitter are necessary for the electronic management of the car through the electronic control unit (ECU), which manage the operation of the engine, as well as the safety and comfort of the vehicle [13].

The vehicle diagnosis is the result of an analysis of the electric functions of the car that are centered in the ECU, which collects information from the electronic sensors that are installed in the car to determine the type of operation that should be applied to other elements through the connection or disconnection of the actuators [14].

From the 2006 models on, the control and verification of vehicle failures is made by automated vehicle diagnosis using equipment such as: scanner, mobile applications, portable devices, all data repair, and so on. [15]; with this equipment we have an accurate assessment of the damage in the engine, but at a significant cost that usually does not have a common user.

### *C. Fault Grouping*

In the field of engine failure diagnosis, two challenges can be identified [16]. The first one is the simultaneous failure, which means that several independent and individual failures appear at the same time [15] and the second challenge is the continuous failures that cannot be detected individually, then the presence of one or more failures is required to improve the accuracy of the diagnosis.

This leads to a problem, it is how to group the information obtained from the multiple signals detected by various types of sensors [16], when a failure arises and then the correct diagnosis.

When reviewing the literature, it is learned that the characteristics of the simultaneous failure patterns can be obtained from patterns of single failure signals in some applications, provided when an adequate technique of extraction of characteristics is used [17]. In this way it can help to identify a symptom of simultaneous failure only by analyzing patterns of single failure [18].

Next, the methodology used in this study is described.

## III. MATERIALS AND METHODS

This investigation began with a literature review regarding engine failures and fault grouping, as indicated in the previous section. Then, it is defined the stages for the construction of an expert system (ES) proposed by [7], which consisted of four phases: (i) knowledge extraction; (ii) writing of the production rules; (iii) creation of the inference engine; and (iv) creation of the user interface.

### *A. Knowledge Extraction*

It begins with the acquisition of knowledge from the expert about automotive mechanics, who makes a first sketch of the information that allows to understand the underlying production rules on which the identification of automotive failures is based.

After the documentary review about failures and sensors of the engine compressed in the central control unit (ECU - Engine Control Unit) and the underlying rules, the faults are identified and grouped according to the type (simultaneous and continuous); and the input of variables to the ES are also defined.

In Table I, it is shown the information organized by group of simultaneous faults and their possible causes, while Table II shows the continuous faults. As explained before, simultaneous faults are understood those that are lit simultaneously or run at almost the same time, in such way that it is almost impossible to identify which sensor or failure affects the vehicle.

It is understood for continuous faults, those that necessarily must have a sequence of failures so that it converges in a single sensor (problem).

TABLE I. GROUPING OF SIMULTANEOUS FAILURES

| Faults | Possible causes | Condition |
|---|---|---|
| Loss of force | Dirty gasoline<br>Spark plug in poor condition<br>Old gasoline and air filters | Yes<br>Yes<br>No |
| Excess of gasoline consumption. | Damaged injector<br>Oxygen sensor in poor condition<br>Air pressure sensor in poor condition | Yes<br>No<br>Yes |
| Increase of gas emission | Failure at the manifold absolute pressure sensor (MAP)<br>Dirty filters of air<br>Dirty injectors | Yes<br>No<br>No |
| Black smoke | Oil change<br>Change of engine wheels.<br>Integral engine repair | Yes<br>Yes<br>Yes |
| Loss of strength for short periods of time | Coil change<br>Change pump or fuel cell | No<br>Yes |
| Noises on the parts of the wheels | Change of brake pads<br>Change of rulimans of the tip | Yes<br>No |
| Hit on the parts of the wheels. | Change of shock absorbers<br>Lack of grease in the moving parts | Yes<br>No |
| Unstable steering wheel or vibrations. | Ball joint replacement<br>Change of terminals<br>Steering box review | No<br>Yes<br>No |
| Hard gear change. | Change of synchronisms inside the box<br>Lever fiber change | No<br>Yes |

TABLE II. GROUPING OF CONTINUOUS FAULTS

| Faults | Condition |
|---|---|
| Spark plug → Oxygen sensor → Excessive fuel consumption, loss of strength of the vehicle. | Yes |
| Air filter→ Air sensor → Black smoke | Yes |
| Gasoline filter→ Battery or fuel pump → Loss of strength | Yes |
| Spark plug wires→ Coil → Detection and loss of force by instants. | Yes |
| Sounds on the rims→ Brake pads → Damage to the disk | Yes |

With the expert professional it also was defined the vocabulary for the common user to achieve a better understanding of vehicle failures, Table III.

TABLE III. VOCABULARY FOR THE COMMON USER

| General terminology (common) | Diagnostic expert terminology |
|---|---|
| Air sensor | MAP Sensor (Manifold Absolute Pressure) |
| Sensor position | CMP Sensor (Camshaft Position) |
| Butterfly Sensor | TPS Sensor (Throttle Position Sensor) |
| Air flow sensor | MAF Sensor (Mass Air Flow) |
| Oxygen sensor | O2 Sensor (Oxygen) |
| Accident system sensor | SRC Sensor Air bag light |
| Tire sensor | ABS Sensor (Anti-lock braking system) |
| Ralenti | Ralenti Sensor (Idle Air Control Valve) |

*1) Facts Base*

It is the first information to be codified and this contains the premises of the information obtained from the expert.

The facts can be by levels or another characteristic, so it was chosen for priority and importance of the sensors. Table IV presents the assigned weighting by group, priority, risk of damage according to the knowledge and experience of experts.

TABLE IV. LEVELS ASSIGNED BY GROUP, PRIORITY, RISK OF DAMAGE AND EXPERIENCE OF MECHANIC

| Importance level | Level value |
|---|---|
| First (Central and high risk) | 2 |
| Second (Secondary and medium risk) | 1.5 |
| Third (Tertiary and low risk) | 0.5 |

The valuation corresponds to the severity of the engine damage, if it is first level, with rating 2 means that the damage directly affects the vehicle and it will stop; the second level with 1.5 rating means the vehicle has failures that can cause sudden stoppages of the vehicle, but it continues in motion; and third level with 0,5 rating means the vehicle presents almost imperceptible failures, consequently it causes slight inconveniences to the driver, but the vehicle continues working.

On Table V, it is presented the sensors which were taken for analysis, they are part of the facts base, founded on Table IV.

TABLE V. GROUPING OF SENSORES

| Level | Possible causes | Condition |
|---|---|---|
| Main | Sensors (Position Sensor)<br>Sensors (Air butterfly sensor)<br>Sensors (Air Sensor)<br>Sensors (Air flow sensor)<br>Sensors (Shock Sensor)<br>Sensors (Oxygen sensor) | 6 |
| Secondary | Sensors (Gas flow sensor)<br>Sensors (Temperature Sensor)<br>Sensors (Sensor of accident systems)<br>Sensors (Tire Sensor)<br>Sensors (Brake Sensor)<br>Sensors (IAC Sensor)<br>Sensors (Time Sensor)<br>Sensors (Spark sensor)<br>Sensors (Supply Sensor)<br>Sensors (Water Sensor)<br>Sensors (Pressure Sensor)<br>Sensors (4x4 Sensor)<br>sensors (Airbag sensor) | 13 |
| Tertiary | sensors (Tire air pressure sensor)<br>sensors (Air conditioning sensor)<br>sensors (Battery charge sensor)<br>sensors (Brake pad wear sensor)<br>sensors (Detonation sensors)<br>sensors (Canistel valve sensor)<br>sensors (Ralenti)<br>sensors (Oil pressure step sensor)<br>sensors (Glow plug sensor)<br>sensors (RMP sensor (Revolutions per minute))<br>sensors (Speed sensor) | 12 |

| | | |
|---|---|---|
| | sensors (Air conditioning sensor) | |
| | Total | 31 |

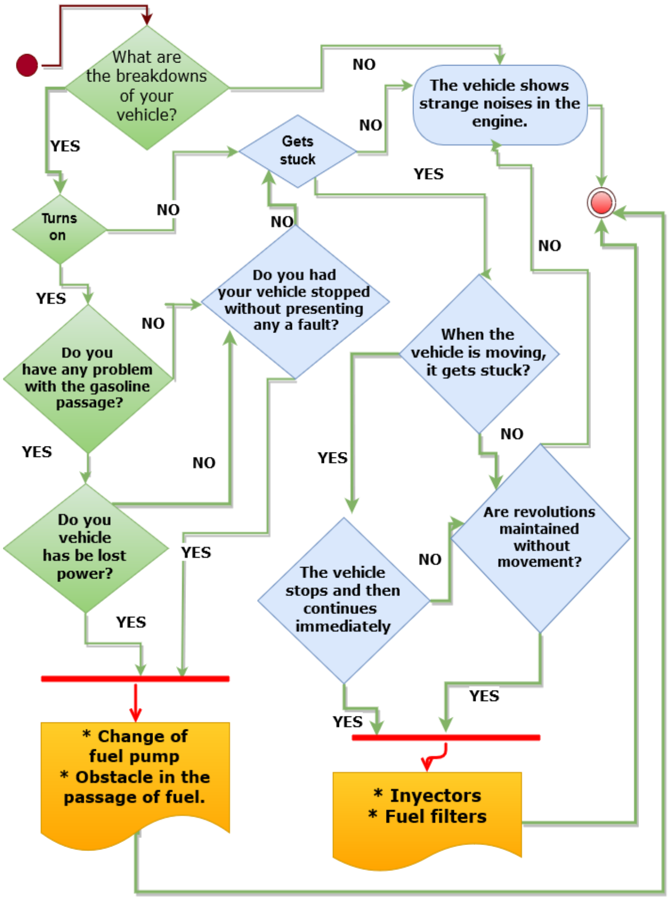


Fig. 1. Flowchart from the production rules

## B. *Writing production rules*

After the construction of the facts base, it is followed with the writing production rules. In this section the graphical writing of the rules is presented by means of a flow chart, (see Fig.1.), which shows the rules for the most recurrent failures, which is visualized through the expert system.

## C. *Inference engine*

The inference engine is the part that reasons about the solution of a problem [19]. Based on a question, it performs interactions, evaluating the knowledge represented in the facts base and the rules base [20] in order to get a coherent conclusion to the problem posed.

For the route of the inference engines there are two search strategies: (i) forward chaining, which is governed by the background of the rules, and (ii) backward chaining that starts from the consequent one that is to be demonstrated.

The chain used in this study is forward by starting with the recognition of the rules first and then continuing with the action or conclusion. García [21] suggests to use two phases in this process: (i) selection of rules and (ii) execution of selected rules. In the first phase three stages are applied: restriction, filtering and conflict resolution for the selection of the rules, while in the second stage the selected rules are executed and stored in the memory of the explanations; this process repeats the system with other applicable rules of the set.

## D. *Creating the user interface*

The user interface is composed of two modules: (i) communications, which allows the expert system to communicate with the web application obtaining general information on automotive parts and the corresponding images; and (ii) explanations, that explain to the user how to identify the failure in the vehicle.

For the user interface development, XP methodology has been used [22] with four phases: (i) Planning, (ii) Design, (iii) Coding, and (iv) Testing.

*1) In the Planning Stage*. Here, it has been identified the necessary hardware and software requirements for the development of the expert system module. In addition, the necessary requirements for connection to the Jdbc [23], which allows the connection to the web application where data will be obtained to feed the fault detection system.

*2) For the Design Stage*. For the design, it has been developed the level 1 diagram (see Fig. 2.), which shows how the expert system module interacts with the user to request information through questions; and with the web application to extract information.

*3) For the Coding Stage / phase*. In the coding, it has been integrated a relational database developed in MySQL, with which the knowledge base and the base of rules were created. In addition, Prolog was used to create the deductive database; the user interface was made with the programming language PHP and Java Script.

The Prolog tool is a logical programming language and is aimed at the specification of relationships to answer queries, so it was conducive to the development of the inference engine.

*4) Tests*. In this phase, the expert system module is unified with the web application for interaction and evaluation of the software with the user through understandable questions, resulting in a report that contains the following: where the failure is located; component that must be changed, if it is the case, image of the damaged piece and the failure information.

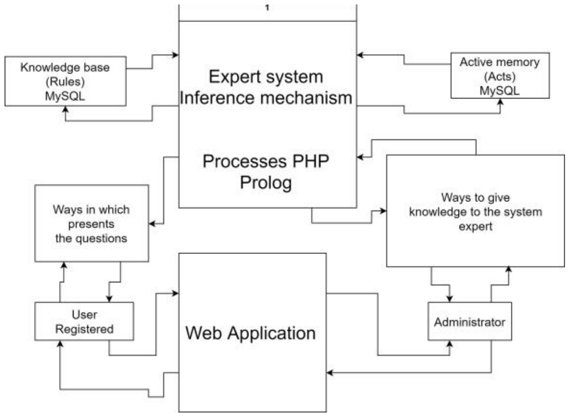


Fig. 2. Level 1 diagram

Next, it is an extract of the questions that the user interface uses to communicate with the user and extract the data from the knowledge base regarding automotive failures Table VI.

TABLE VI. QUESTIONS - USER INTERFACE

| N° | Questions | Localized fault and SE coding | Number of failures |
|---|---|---|---|
| 1<br>2<br>3<br>4<br>5<br>6<br>7 | Do you have problems with the gasoline passing?<br>Did your car stop without showing any failure?<br>Has your car lost power?<br>Does the vehicle get stuck when walking?<br>Does your vehicle lack power when climbing slopes?<br>Does the engine try to turn on, but not turn on?<br>Does the vehicle stop and then continues? | Gasoline: change fuel pump | 1 |
| 1<br>2<br>3<br>4<br>5<br>6 | Do you have problems when the vehicle is working?<br>Does your vehicle stop and continue at once?<br>Do the revolutions not keep steady?<br>Does not let the vehicle accelerate?<br>Does the vehicle not stay on and suddenly turn off?<br>Is there lack of vehicle power? | Gasoline sensor: Engaso | 2 |
| 1<br>2<br>3<br>4<br>5<br>6<br>7<br>8 | Did the car stop?<br>Is the vehicle going but fails and gets stuck?<br>Has the power of the vehicle decreased?<br>Do you try to start with the key but the car does not start?<br>Does the engine have a different sound and lose power?<br>Does the engine burst and does not accelerate?<br>Does the engine have an internal knock?<br>Do the revolutions not rise more than 2000 rev / sec? | Main sensor: Main-sen | 3 |
| 1<br>2<br>3<br>4<br>5<br>6<br>7<br>8 | Does the car have a gasoline smell?<br>Do you consume more gasoline than usual?<br>Do the revolutions increase and decrease without accelerating the vehicle?<br>Is the vehicle accelerated without having pressed the accelerator?<br>Do you consume more gasoline?<br>Are the revolutions not kept in a single value?<br>Do the revolutions not exceed 2000 rev / sec?<br>At the time of stopping the vehicle is not in Ralenti? | Air sensor: senior | 4 |
| 1<br>2<br>3<br>4 | Does the vehicle loss power?<br>Does the vehicle burst when accelerating?<br>Is the coil heating up?<br>Does it have a spark or short circuit making noise on the spark plugs? | Distribution sensor: sen_distr | 5 |
| 1<br>2<br>3<br>4<br>5<br>6 | Does the engine explode towards the intake manifold?<br>Does the motor have no power and the sound is irregular?<br>Does the engine not accelerate and burst?<br>Does the fan sound hard?<br>Does the gasoline meter not mark?<br>Does the LED of the gasoline icon light up? | Electrical sensor: sen_elect, | 6 |
| 1<br>2<br>3 | Does the temperature rise?<br>When the vehicle stops, does it release water?<br>Does the fan not turn on when the temperature is already high? | Temperature sensor: sen_temp | 7 |
| 1<br>2 | Is the oil sensor LED turned on for a short period of time?<br>Does the oil sensor led stay on? | oil sensor: - sen_acei, | 8 |

The data analysis for knowledge extraction shown in the tables I-IV and the flow chart (Fig. 1) contributes in the result of the expert system module for vehicle failure detection.

The route test starts with the first question corresponding to the verification of damages in the car, then the route is followed according to the flow chart presented in (Fig. 1.), according to the questions presented in Table VI, the route ends with the diagnosis of the failure presented in (Fig. 3.).


Fig. 3. Starting point of the expert system tour

The data in Table VII present the following route through the expert system: in column 1 there are the questions that the expert system made, in column 2 the user responses indicated with bold and underlined, in column 3 the weighting of each question presented in Table IV, and finally in column 4 the value assigned by each true answer (YES) according to Table IV. The zero value was assigned for each negative answer (NO).

TABLE VII. INTERACTION OF THE EXPERT SYSTEM - USER - FOR THE DIAGNOSIS OF FAILURES.

| **Question chosen by the system** | **User Response** | **Assessment by Question** | **Valuation according to answers chosen by the user** |
|---|---|---|---|
| Do you have problems with the gasoline passing? | **YES** or NO | 2 | 2 |
| Did your car stop without showing any failure? | YES or **NO** | 2 | 0 |
| Has your car lost power? | **YES** or NO | 1.5 | 1.5 |
| Does the vehicle get stuck when walking? | **YES** or NO | 1.5 | 1.5 |
| Does your vehicle lack power when climbing slopes? | **YES** or NO | 1.5 | 1.5 |
| Does the engine try to turn on, but it does not? | YES or **NO** | 0.5 | 0 |
| Does the vehicle stop and then continue? | **YES** or NO | 1.5 | 1.5 |
| Solution | Total | 10 | 8 |

In (Fig. 4.), the diagnosis result is shown containing the graph of the part with damage and the recommendation or solution.


Fig. 4. Result of the failure diagnosis of the example in Table VII

The ES was carried out with the collaboration of experts from the companies: *TecniAuto* from Espejo canton (Ecuador), which has been dedicated to automotive mechanical maintenance for 35 years, the owner is a skilled professional craftsman; its clients are people from public and private companies; and *Remachadora del Norte* from Ibarra city (Ecuador), which is dedicated exclusively to the sale of spare parts, and has 25 years of experience in the advice and sale, its customers are mechanics and private individuals.

To validate the proposal, it has been applied a survey to several clients of the two companies. The population surveyed were people who used the services of the two companies; it was considered four working days (01 - 04 July), two days in each company, the Table VIII, presents the data by company, total population and users who collaborate with the tests of the expert system module.

TABLE VIII. USERS WHO VISITED THE COMPANY AND MADE USE OF THE EXPERT SYSTEM

| **Company** | **Company Code** | **They did the test** | **they didn't do the test** | **Total** |
|---|---|---|---|---|
| TecniAuto | Emp1 | 7 | 3 | 10 |
| Remachadora del Norte | Emp2 | 14 | 6 | 20 |
| **Total** | | **21** | **9** | **30** |

## III. RESULTS AND DISCUSSION

Table VIII shows the number of users who visited the establishments on the consigned days, they were approached minutes before using the services of the collaborating companies (*TecniAuto* and *Remachadora del Norte*). Users were informed about the purpose of the expert system module (ES). Also, it specifies the number of people who collaborated and those who did not use it because of time.

Tables IX and X show the results of the successes and disappointments between the expert module and the technicians specialized in the automotive area. The users have been designated by code M (Men) and W (Women) and the number is the order of visit, the skipped numbers imply that the user visited the place but did not use the ES.

TABLE IX. RESULTS OF COMPANY 1 (DAYS 1 AND 2)

| **User code** | **Expert System Solution** | **Automotive Mechanic Solution** | **Success** |
|---|---|---|---|
| M1 | Change of gas filters | Change of gasoline filters | YES |
| M3 | Change of the gasoline pump | Cleaning of injectors | NO |
| M4 | Change of temperature sensor | Change of temperature sensor | YES |
| M5 | Change of Position Sensor (head or cylinder head) | Defective position sensor | YES |
| M6 | Change the motor position sensor (block) | Cleaning the sensor by being dirty the sensor | NO |
| M7 | Change of the MAP sensor or change of the air sensor. | Cleaning dirty MAP sensor | YES |
| M9 | Change accessory pump | Change accessory pump | YES |

To the first company 10 users came (9 men and 1 woman), of the total 7 performed the test, Table VIII. In Table IX it is observed that the ES was not successful with the mechanic's diagnosis in two cases. The first performed by user M3, it is because both faults have the same symptoms and characteristics, in this case, it is essential a physical review of the vehicle to corroborate the failure, according to the mechanical expert, first it begins from the assessment of the following parts: pump pressure, there is a spark in bugs, lack of gasoline and pump pressure.

In the following error, user M6, the ES suggests the change of the sensor of position of the engine, but the mechanic when verifies the sensor identifies that it is not burnt, and it is full of slag and makes difficult the passage of the sensor signal to the ECU, so it suggests carrying out magnetism tests and if it complies with the values that the sensor must send to the ECU, then the procedure is cleaning the sensor and not changing it.

TABLE X. RESULTS OF COMPANY 2 (DAYS 3 AND 4)

| User code | Expert System Solution | Automotive Mechanic Solution | Success |
|---|---|---|---|
| M1 | MAP sensor change (air pressure collector) | MAP sensor change | YES |
| M2 | Changing the airflow sensor | Cleaning or change of air filters | NO |
| M4 | Change of temperature sensor | Change of temperature sensor | YES |
| M5 | Change of IAC sensor (air control valve) | Changing the IAC sensor | YES |
| M6 | Change of coil or inspection of spark plug wires | Coil change | YES |
| M7 | Change of thermostat and temperature sensor | Change of the thermostat | YES |
| M8 | Spark plug wire cabinets Change | Spark plug wires change | YES |
| M11 | Change of oxygen sensor | TPS sensor change | NO |
| M12 | Changing the TPS sensor | Changing the TPS sensor or poorly calibrated | YES |
| M13 | Change of oxygen sensor | Change of oxygen sensor | YES |
| M15 | Change of coil or spark plug wires | Spark plug replacement | YES |
| M17 | Change the fuel pump | Change fuel filter | NO |
| W2 | Changing the TPS sensor | Calibrate.<br>Badly calibrated the TPS sensor | NO |
| W3 | Change of pump | Change of pump | YES |

To the second company 20 users came (17 men and 3 women) in two days, of the total, 14 took the test, Table VIII. Table X shows that the ES did not coincide with the diagnosis of the expert mechanic in four cases.

In the first case with the user M2, the ES did not hit due to the fact that any filter either of air or fuel can cover up or get dirty which generates a failure in the closest sensor to the flow of air or gasoline in these circumstances the solution of an expert mechanic recommends cleaning, while for the ES suggests changing the piece.

In the tests of M11 and W2, the ES, does not precise with the diagnosis of the mechanic, but it locates the place where the fault occurs, these errors are in simultaneous failures since as mentioned above they are difficult to detect and most of them it gives false positives, due to the oxygen sensor's dependence on the functioning of the TPS sensor.

The last fault of the ES made with M17, it is aimed at verifying the flow of the fuel flow since the fuel flow can be obstructed, this is because the air and fuel filters do not have sensors that are capable to report accurately.

As mentioned earlier, the test was carried out on 21 people from the 30, Table VIII, who attended the workshops in four days, the results show that there were a total of 15 hits and 6 mistakes of the expert system, Tables IX and X, that is, the project has a 71,43% effectiveness. On the other hand, 28,57% represents that the module of the expert system has limitations in terms of the diagnosis of simultaneous failures, in the electrical system of exterior lights in automobiles and where sensors for evaluation are not found.

### *A. Discussion*

The expert systems (ES), coinciding with the statement by [21], are excellent tools in situations in which a fact has the Boolean option of YES or NO, due to compliance with a rule, in this case with the interrogation of several questions adequately designed by an expert it can get to determine car failures without the assistance of an auto mechanic.

With the research carried out it can be determined that an ES, despite having lost field due to the presence of other very efficient techniques for decision making, such as machine learning, data mining [11], mathematical methods [9]; ES are still useful in solving a problem in a specific field where knowledge can be stored and further increased as necessary in the knowledge base, as well as indicated [10], the improvement and precision in the diagnosis of car failures is an area open to research.

The ES, reviewed here, are excellent contributions for technicians and students in the mechanical area [9], [3] and [24], since it makes a diagnosis of the vehicle from the start-up; the expert ES raised here is an innovative application because it helps the common user to discover the fault and where it is located.

Finally, and from the experiences gathered in the present investigation, it is suggested as future work to carry out the diagnosis with a larger number of customers, as well as the through the implementation of fuzzy logic in the ES to improve the detection of simultaneous faults; and the design of a mobile application (App).

## IV. CONCLUSSIONS

The present work proposes an expert system module (ES) for the diagnosis of automotive failures without the technical assistance of an automotive mechanic. The ES consists of four stages: (i) knowledge extraction; (ii) creation of the inference engine, (iii) writing of production rules, (iv) creation of the user interface, proposed by [7]. The ES identifies where the failure or damaged piece, to support the user to have a concise communication with the mechanical expert for the quick car repair.

All car engines from 2006 use electronic system that allows the effective development of the ES module because each sensor is susceptible to assessment and identification, this advantage made easiest the acquisition of information to power the ES, subsequently the grouping of failures (Tables I and II) and the identification of sensors by levels (Table V) made ES recognize a total of 93 failures easily, demonstrating that the ES is applicable for all vehicles that have electronic injection systems: mono and multipoint.

The development of the ES test with simple questions (Table VI), with customizing vocabulary for the user (Table III), tested with clients of the collaborating companies (Table VIII), and comparisons of answers between the ES and the expert in mechanic (Tables IX and X) have revealed that the ES module developed for common users has been successful in diagnosing vehicle failures in most cases, thus verifying its effectiveness.

This work is dedicated to ordinary people without knowledge of mechanics, using simple questions, (Tables III and

V); until reaching the diagnosis, (see Fig.4.) In addition, it can be helpful for an expert as an assistant in the assessment of vehicle damage, reducing work time and costs for checking.

As future work, it is suggested the incorporation of fuzzy logic in the ES to improve the detection of simultaneous faults; and the design of a mobile application for ordinary users.


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