

## ELECTRIC FUEL INJECTION ENGINE RELIABILITY PROBLEMS IN DEVELOPING COUNTRIES, CAPE VERDE CASE STUDY

Carla Merícia Monteiro Tavares, Janusz Szpytko

AGH University of Science and Technology  
Department of Mechanical engineering and robotics  
Adama Mickiewicza Avenue 30, 30-059 Krakow, Poland  
e-mail: monteiro@agh.edu.pl, szpytko@agh.edu.pl

### Abstract

Due to the need to reduce greenhouse gas emission rate, nowadays vehicles are manufactured in different types of fuel injection, one example is the engines with electronic injection and management. These vehicles present several advantages for the environment and it reduces the amount of fuel used in the vehicle, becoming more economic, what is also important due to the prediction for decrease of the available quantity of fossil fuel. The mechanical injection vehicles are no longer manufactured what make the electronic fuel injection engines to begin to be introduced in Cape Verde. The biggest problem in Cape Verde, when it comes to maintenance of vehicles, is the fact that the majority of mechanics working in vehicles maintenance, learned with the practice, very few of them had the opportunity to study. These new vehicles require staff with a certain level of knowledge. Mechanics and workers generally have an elementary school education; or have never finished high school. Many of them began working as apprentices and were trained on the job by more experienced staff. As a result, most of their skills were acquired on the job in practical "hands-on" contexts without any theoretical training. This paper aim to study the state of the art related to maintenance problems and strategies in electronic fuel injection engines, as well as the study of problems faced in Cape Verde with the maintenances. This paper will propose a solution for a reliable maintenance, for these devices in countries with lack of technical support focusing in the study of case in Prai city, Cape Verde.

**Keywords:** electric fuel injection engine, maintenance, reliability, developing countries

### 1. Introduction

The global energy consumption has been increasing, currently fossil fuels account for 87 percent of global energy consumption. Among the three types of fossil fuels (oil, gas, coal), oil is the major source of primary global energy consumption [3]. However, they introduce greenhouse gases into atmosphere and could be ecologically damaging. There is an indication that the growth in world fossil production is likely to cease after 2025 [10]. In order to reduce greenhouse gases emission and reduce fuel consumption new vehicles technologies has been developed [13]. One example is vehicles with electronic fuel injection system, this vehicles has an electronic ignition system with a complex engine management systems, equipped with various sensors.

The electronic fuel injection provided an evolution in the entire system. Allows economy of fuel, highly improved performance of the vehicle, less emission to the environment and higher reliability. With the increasing complexity of mechatronic solutions, diagnosis becomes a major theme for improving safety and reliability [4]. The diagnostic system is responsible for the detection, localization and determination of the size of the fault in the vehicles.

The maintenance of vehicles with electronic fuel injection system require experts familiar with the equipment, and special equipment able to perform the diagnosis procedure and interpretation of fault in the vehicle.

Vehicles with new and sophisticated technologies as electronic fuel injection system began to be introduced in developing countries. Most of the developing countries are characterized for been highly disadvantaged in their development process requiring special support from the international community due to the challenges faced as high costs for energy, infrastructure, transportation and

communication [11]. The introduction of these new vehicles in developing countries is an issue that need attention.

This paper aim to study the state of the art related to maintenance problems and strategies for electronic fuel injection engines, as well as the study of problems faced in Cape Verde with the maintenances. This paper will propose a solution for a reliable maintenance, for these devices in countries with lack of technical support focusing in the study of case in Praia city, Cape Verde.

## 2. Electronic fuel injection engine

The requirements of present-day transport systems become more and more complex; have new technology applications in the vehicle, the infrastructures, and in logistics will accelerate developments. Comfort and security under operation, engine performance and emissions, as well as design play a significant role for developers and user. Especially modern automobiles have to correspond to these demands [4]. Vehicles with environmentally friendly technologies are been developed constantly, many cars company are investing in new technologies in order to comply with emission regulation. Nowadays vehicles are manufactured with different fuel injection. Fuel injection is part of the engine control system, this system regulate the intake air, fuel and spark timing in order to achieve the desired performance in form of torque or power output [2]. Early fuel injection was based in mechanical principles; nowadays the system used in the vast majority of the vehicles is the electronic fuel control system.

Since 1986, diesel injection systems have been increasingly equipped with digital electronic control systems. In the beginning, mechanically governed distributor pumps were used. As of 1987, inline pumps with electronic controllers were used to recirculate exhaust gas and control the fuel quantity. The most important features of electronic engine control are its high availability throughout a vehicle's entire life, full functionality even under extreme environmental conditions and real-time operation in every operating state and at every engine speed [12].

With the availability of electronics, automotive, electronic ignition systems became available. The evolution of these systems leads to complex engine management systems, equipped with various sensors [4]. The use of sensors in a motor vehicle requires a high level of sensitivity toward mechanical, climatic, chemical and electromagnetic influences. The most important sensors and their functions for diesel engine control are shown below in the Fig. 1 [12]. The electronic fuel injection system, allows a more effective control of the mixture admitted to the engine providing more economy of fuel, the engine always works with the proper mixture and better performance.

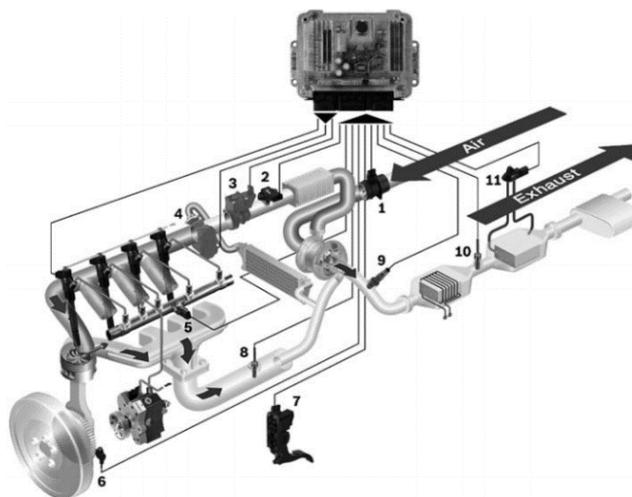


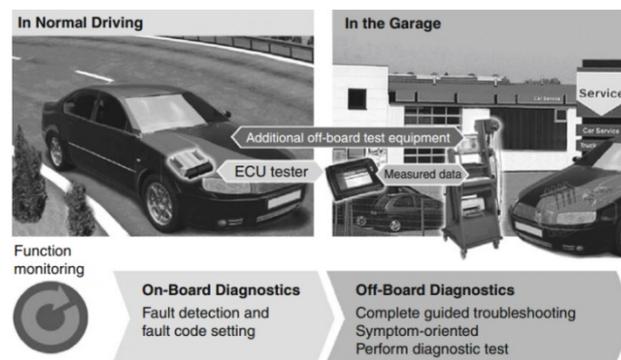
Fig. 1. System diagram of diesel engine sensors: 1 – air mass sensor, 2 – boost pressure sensor, 3 – butterfly valve, 4 – exhaust gas recirculation valve, 5 – rail pressure sensor, 6 – speed sensor, 7 – accelerator pedal module, 8 – exhaust temperature sensor, 9 – Lambda sensor, 10 – exhaust temperature sensor, 11 – differential pressure sensor [12]

The safety of individuals and, above all, vehicle's passengers is top priority for the design of electronic systems. Therefore, the control unit includes a monitoring concept, which enables safely controlling a vehicle even in the case of a fault, should another controllable system reaction no longer be possible, the engine is cut off [12].

The introduction of vehicles with electronic management and fuel injection offered increased functionality by combining existing separate subsystems to perform higher-level functions in an integrated system. This provided an evolution in the entire system, resulting a highly improved performance of the vehicle, less emission to the environment and higher reliability. The electronic fuel injection system implies new and more sophisticated control strategies. With the increasing complexity of modern systems, diagnosis becomes a major theme for improving safety and reliability [4]. The maintenance strategy applied to vehicles with electronic fuel injection and management is mostly preventive maintenance. Corrective maintenance is much more expensive.

This modern electronic controlled engine has a sophisticated computer processing power. This type of sophistication present within the vehicles, are bringing a new concept of maintenance for vehicles, many shops struggle when it comes to repairing the modern fuel injection system. They are necessary techniques to diagnose these sophisticated vehicles quickly and accurately; and do so in a way that allows the shop to make money [2].

Monitoring and diagnostics are performed during in-use driving without auxiliary equipment and belong to the basic scope of electronic engine control systems. Part of monitoring and diagnostics during in-use driving (on-board diagnostic) is ensuring that the system state is controllable to prevent consequential damage in a fault scenario. When necessary, such default responses employ default functions/values to control operation or cut off an engine in serious cases [12]. Detected faults are stored in the control unit's fault memory and can be exported through a serial interface, which is usually specific to the manufacturer. The diagnosis procedure and interpretation of fault in the vehicle is done by experts with special equipment (off-board diagnostic).



*Fig .2. Diagnostics and monitoring in in-use driving and garage diagnostics [12]*

### **3. Vehicles maintenance**

The propose of maintenance is to find both technical and organizational solutions. The huge cost and risk related to improper maintenance has been both observed and documented in the industry [6]. In order to design a maintenance strategy for a system, it is necessary first to know the system, to go deeply to understand the functioning of the system, for this it is necessary to define the input and desired output of the system, it is necessary to define some actions based on the functioning of the system.

The key areas that has influenced maintenance in this last 40 years according to the e-maintenance book, is the management of people and assets, and technological capability. Before defining the management, strategy to apply is necessary to create a management strategy in a way that can predict the future of the machine [6].

Vehicles fleet maintenance management, has a direct influence to the vehicle maintenance process, the primary transport process, and the environment. For an efficient fleet maintenance management it is necessary to observe jointly: The transport process as a primary (core) process that brings profit to the company; The vehicle maintenance, as logistical support to the core transport process, which by means of maintenance interventions transforms vehicle condition from the state of “unready for operation” to the state “ready for operation”; The environment, associated to safety and environmental protection from the maintenance impact, which is monitored via technical inspections [8].

The objective of vehicle maintenance process is to decrease its environmental impact through superior quality of maintenance intervention. The recent appearance of new car technologies signifies that there is currently scarcity of experts familiar with the unique design and characteristics of the vehicles. This lack of skilled personal is a problem for the maintenance of these vehicles [1].

Vehicles manufacturers, afford a maintenance programs in a manual. To ensure proper and safe functioning of the system it is necessary to know the vehicle maintenance manual, it's necessary to follow and check the maintenance that must be performed, and do it in the correct time. Maintenance must be performed by a qualified professional, and with appropriate equipment's.

The electronic injection engine is continually developing, it has components that handled in improperly way, can be damaged. The owners of the vehicles should opt for preventive maintenance. Corrective maintenance is much more expensive, one example if the fuels filter is not changed at the right time, and it can cause burning of the fuel pump that is much more expensive.

The optimal maintenance strategy is strongly affected by the cost and effect of the maintenance as aging [9]. In vehicles with electronic management system, monitoring and diagnostics are performed during in-use driving, the OBD (on-board diagnostics) system, monitor systems and components relevant to emissions [12].

As mentioned before the diagnosis in electronic vehicles is realised on-board and off-board. The off-board diagnosis is realized in the garage (repair shop); the diagnostics is for rapidly and positively localizes the smallest replaceable unit. The use of a diagnostic tester, which is usually computerized, is absolutely essential in advanced diesel engines [12]. A garage employee is guided through fault diagnostics with the aid of a diagnostic tester where the test results are generally evaluated.

In recent years, vehicles with electronic engines began to be introduced in Cape Verde, but still, most of the vehicles with mechanical injection system. The vehicles with electronic engines present several advantages for the environment and are more economic [1], but for developing countries as Cape Verde, have lack of expertise and tools for the maintenance operation, these vehicles have faced big problems specially related to maintenance.

#### **4. Maintenance of public transport in Cape Verde**

Cape Verde is an archipelago in the Atlantic Ocean, near to the west coast Africa. It consists of ten islands. Praia is the capital city of Cape Verde, located in Santiago Island. Praia city has been experiencing an extremely rapid growth leading to increasing needs to travel from one point to another, generating an increase in movement of means of transport.

Cape Verde is defined as a small island developing states (SIDS) that are a distinct group of developing countries facing specific social, economic and environmental vulnerabilities. They are highly disadvantaged in their development process requiring special support from the international community due to the challenges faced as high costs for energy, infrastructure, transportation, communication and so on. Devising innovative approaches and improving the management and maintenance of existing transport and communications infrastructure to resolving transport and communications problems are major challenges to the SIDS [11].

The carrying on of the public transport activity in Cape Verde needs license; this is given by the services for road transport, or the Municipal Chamber. The vehicles must be subject to inspection in services for road transport, or in Private Canter's ITVA (Inspection Technique of Motor Vehicles), these make inspection of the vehicle operation without checking the engine, if the vehicle does not have conditions to be approved in the inspection, this will be forwarded to a mechanical workshop, which will have to carry out the verification and correction, after, the vehicle is again subjected to inspection for obtaining the license [7].

Into the Praia city, the main activity of public transportation is fulfilled by the Bus Company, taxi and Hiace. The maintenance Services for each type of public transport mentioned, depends on the owner decisions. The vehicles belong to private companies and individual persons. Usually, private companies, owns their maintenance workshop, with mechanics that can provide the maintenance services to the vehicles. Very often they have problems in finding some engine components for maintenance, they need to order the parts to a store, or from another country, most of the time it's necessary to wait more or less 2 moth, for the parts to arrive, for the replacement and repair in the vehicles. In other situations, they prefer to make some adaptations rather than wait. The Public transport belonging to individual person as taxi and Hiace, visit an external mechanic workshops for maintenance services.



*Fig. 3. Public transport in Cape Verde: 1 – Taxi, 2 – Bus, 3 – Hiace*

Most of the public transport in Cape Verde is subject to corrective maintenance. The preventive maintenance is not used much. Usually vehicles are sent to the maintenance when presenting some type of fault. This practice has brought several inconvenience to traffic in cities. Very often, a car just stops working in the middle of traffic, this brings traffic congestion and displeasure to passengers and drivers. The lack of proper maintenance in vehicles has caused major accident, which shows that a proper maintenance on vehicles is a subject of a major importance; a proper maintenance procedure makes a big difference. Preventive maintenance extends the life cycle of the vehicle, preventing further damages.

Cape Verde is facing now a new challenge regarding to maintenance of vehicles with electronic injection system. There is a need of equipments necessary for the maintenance of electronic vehicles and professionals with knowledge and adequate training. Due to the lack of conditions for an reliable and efficient maintenance, owners opt to replace the engine of the vehicles, they change the electronic for the mechanical injection, because the maintenance is very difficult in the country, very often when there is a failure in the vehicle, this has to stop the operation. The stop of operation of the vehicle transport brings much cost and inconvenient for the owner and users, the device will not be able to fulfil its task.

Some workshop maintenance companies, started to invest in equipment's for fault detection, of vehicles with electronic engines, but still many operators of the equipment do not have enough knowledge and formation in how to use it. According to Luisa Tavares, who was student in the area of automobile engineering in the Polytechnic Institute of Leiria in Portugal, and today is responsible for the maintenance of automobile in the company Filipe Auto in Cape Verde, the country needs not only equipment but also qualified staff with necessary training. It is necessary to bring the equipment, train the professionals and to educate the population about the importance of preventive maintenance for vehicles.

In Cape Verde all, the vehicles are imported from abroad (Asia and Europe). Cape Verde is not ready to ensure a proper maintenance for vehicles with electronic injection engines, but there is no other option for those with a wish to acquire new vehicle, vehicles with mechanical injection are no longer manufactured. The reason is necessary to find a solution for this problem. The corrective maintenance is rather impossible, first is necessary to detect the fault them to correct, and there is a lack of equipment's and professionals able to accomplish this task.

In Cape Verde, majority of mechanics working in vehicles maintenance, learned with the practice, very few of them had the opportunity to study. These new vehicles require staff with a certain level of knowledge. Mechanics and workers employed in garages and repair shops generally have an elementary school education or have never finished high school. Many of them began working as apprentices and were trained on the job by more experienced staff. As a result, most of their skills were acquired on the job in practical "hands-on" contexts without any theoretical training.

The level of expertise is the most important facet of a panel member of a maintenance workshop (Hallowell & Gambatese, 2010). The qualifications of the panel members are the following: Master's Degree in Occupational Risk Prevention, Bachelor's/ Master's Degree in Engineering, Extensive professional experience [8]. The panel members of a maintenance workshop in Cape Verde is composed mostly for professional experience, in companies more developed with financial stability it's possible to find professional with Bachelor's / Master's Degree in Engineering and/ or Occupational Risk Prevention.

The most used public transport in Praia City; Santiago Island in Cape Verde is bus. One example related to maintenance of vehicles with electronic injection in Cape Verde might be the recent problem faced by the company that provides public transport service in the city, Sol Atlántico Bus Company.

The Sol Atlántico bus company, has been growing a lot in recent years, there is a substantial investment in improving the fleet and maintenance services. Today the sol Atlántico Company has a modern maintenance workshop, a fleet of about 40 buses. The company recently invested in 10 new buses, of which just over one year, all with electronic fuel injection system. Recently they had problem with one of the new vehicles, but they could not even detect the problem because, they do not own the equipment for detection of malfunctioning in the vehicle, and their mechanics has no knowledge how to handle problems related to this vehicles.

A solution to the maintenance problem faced by the bus company Sol Atlántico was to keep going until it will be possible to solve the problem, for now they are trying to purchase the equipment for fault detection. In their panel members of a maintenance workshop, they just have workers with professional experience; the purchase of the equipment is not a guaranty for the solution.

## **5. Maintenance strategy proposal**

Taking as case of study the public transport in Cape Verde, in Praia city the main activity of public transportation is fulfilled by the Bus Company, taxi and Hiace. In the city operate two private companies of urban transport of passenger (bus company), Sol Atlántico and Moura Company. Nowadays the sol Atlántico is the main company for delivery of bus service.

The definition of the strategy for an reliable maintenance for the tree type of public transport mentioned, has to take in consideration the management of delivery of the means of transport, this has to be in a way that can ensure the populations need of transport, the safety of the passengers and a reliable transport system. This practice will contribute for the environment protection by reducing the number of empty vehicles in the road, and control the emission of the CO<sub>2</sub>. A good maintenance strategy is very important to ensure a reliable functioning of the transport network in the city. The country is facing now a new challenge regarding to maintenance of vehicles with electronic injection system.

The number of these vehicles is growing very rapidly, it is necessary to create a strategy that can solve this problem before it becomes chaotic. Most of garages in Cape Verde are not prepared to provide maintenance for these vehicles, but there are some workshops investing in new equipment's and professionals apt to use the required equipment's for fault detection in this new vehicles. This information's give the propose a solution for the management of maintenance for vehicles with electronic fuel injection, and also contribute to enhance and increase the productivity of the most advanced workshops in the city while others workshop prepare and arrange to have condition to join this solution latter.

For the creation of a strategy to solve the faced problem with maintenance in vehicles with electronic fuel injection and management, first is necessary to collect some important information's as:

How many and characteristics of vehicles with electronic injection and management system is in the country, and how many is entering in the country (control of the movement of this vehicles in order to manage the need for maintenance); How many repair workshop are ready to perform the maintenance procedure in these vehicles; what are the conditions the repairs workshop can offer, a study related to all repair maintenance shop is needed in order to know the installations that gather the necessary conditions to carry out the maintenance task of these vehicles (available equipment's and personnel with formation and knowledge). After collecting information's, it is necessary to know and define which vehicles each workshop are ready to receive in order to offer an efficient and reliable maintenance service program, and how this program will be done.

In order to make the collected information and strategy available for all, to support and manage the maintenance of these vehicles, it is necessary creation of a platform containing all-important Information's for owners of vehicles and repair shops. In this platform is possible to see where they can take their vehicles for maintenance. Nowadays there is no place with such information's, there is a lack of information's related to where people can take those vehicles to maintenance, no attention is paid to maintenance operation of vehicles.

All vehicles should be subject to preventive maintenance, in this way is possible to prevent the need for vehicles components for replacement. The maintenance function plays a critical role in a company's ability to compete based on cost, quality and delivery performance. This solution will give another view for maintenance in the country and decrease the problem related to maintenance of vehicles with fuel injection. These vehicles are developing day by day, it is necessary to establish a formation program for all engineers and technicians working in this field in order to guarantee a quality of service.

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