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Applying Total Productive Maintenance to Body Control Modules (BCM) in the Automotive Industry: Optimizing Reliability and Preventing Failures

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Abstract - The paper analyzes the application of the Total Productive Maintenance (TPM) method on the Body Control Module (BCM), used in the automotive industry. By integrating preventive maintenance and reliability analyses, the aim is to reduce unplanned shutdowns and optimize system performance. The study is based on real data and highlights the benefits of TPM in the context of automotive electronics, but also the limitations encountered in practice. The contribution of the paper consists in highlighting an approach model applicable to the maintenance of complex electronic components.

Keywords: Total Productive Maintenance (TPM), Body Control Module (BCM), preventive maintenance

I. INTRODUCTION

In the context of the modern automotive industry, the efficiency and reliability of electronic equipment and components are becoming increasingly important, both for manufacturers and users. The Total Productive Maintenance (TPM) model is used by scholars and practitioners alike to avoid losses and increase productivity [1].

A prime example is the Body Control Module (BCM), an essential module that controls numerous electronic functions of the vehicle body, ensuring comfort, safety and optimized communication between various vehicle systems. This important part has been researched over the years, with the purpose of improving the testing part or focusing on it in the security analysis [2], [3], [4].

The present study aims to apply TPM to BCM to ensure optimal operation and minimize downtime. In this line of reasoning, a rigorous maintenance strategy is required, and the Japanese concept of TPM provides a complete framework for achieving this goal.

II. METHODOLOGY

This paper presents applicative research, focused on the analysis of the implementation of the Total Productive Maintenance (TPM) concept within a maintenance department of an automotive component manufacturing company, located in western Romania. The methodology used involves theoretical documentation regarding TPM and BCM, direct analysis of the processes within the company, as well as practical observation of the maintenance of BCM modules.

This paper aims to analyze the implementation of TPM principles in the maintenance process of BCMs, focusing on reducing downtime and improving product quality and safety. Through a thorough understanding of preventive maintenance processes and specific BCM issues, effective solutions can be identified to ensure an extended component life and optimized production.

III. THE RESEARCH APPROACH

3.1 Conceptual aspects regarding TPM

The TPM concept became an innovative Japanese concept in the 1950s, a concept taken from the United States. Thus, preventive maintenance combined with maintenance prevention and maintenance improvement came to a new concept called productive maintenance. The goal of productive maintenance was to maximize the efficiency of facilities and equipment to achieve reliable and optimal life cycles of production equipment. [5]

The types of preventive maintenance are as follows:

- Systematic maintenance - is carried out through maintenance activities, current repairs, revisions, established in a specific ethnic plan for each type of equipment.
- Conditional maintenance - carried out by monitoring the wear parameters of the elements, using specific tools, so that

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maintenance is carried out before the appearance of the defect.

- Predictive maintenance - allows the delay and planning of interventions, preventive maintenance being subordinated to the analysis of the evolution following the degradation of the asset [6].

The initial objective of TPM is to return the equipment to its new condition and to prevent any further deterioration. The implementation of preventive maintenance (PM) programs is the first step towards eliminating deterioration. A four-stage approach to PM programs is presented in Fig. 1 [5].

In the four-phase PM program development, the first phase consists of inspecting the target equipment, using customized checklists, and labeling and documenting the problems. The second phase involves prioritizing the identified problems and identifying the causes of the highest priority problems. Tools commonly used in this phase include brainstorming, data collection, and maintenance/operator experience. In phase 3, the focus is on developing inspection standards and building PM programs. Inspection standards should be written standards. These are essential for developing accurate PM programs. They should communicate the procedure required to perform PM effectively. Finally, the fourth phase consists of providing training, implementing PM programs, and monitoring and adjusting. Effective training should be developed and provided to the targeted operators and maintenance personnel. This is necessary for effective PM implementation.

Autonomous maintenance involves the development of preventive maintenance practices. For equipment improvement, equipment activities should focus on eliminating all failures through physical equipment analysis (PEA) techniques to aim for zero failures. For preventive maintenance systems, the organization should develop an information system that contains all TPM activities. Equipment-related decisions are then based on maintenance and performance data. Finally, quality maintenance focuses on eliminating equipment-related failures through physical quality analysis (PQA). The goal is zero defects [5]

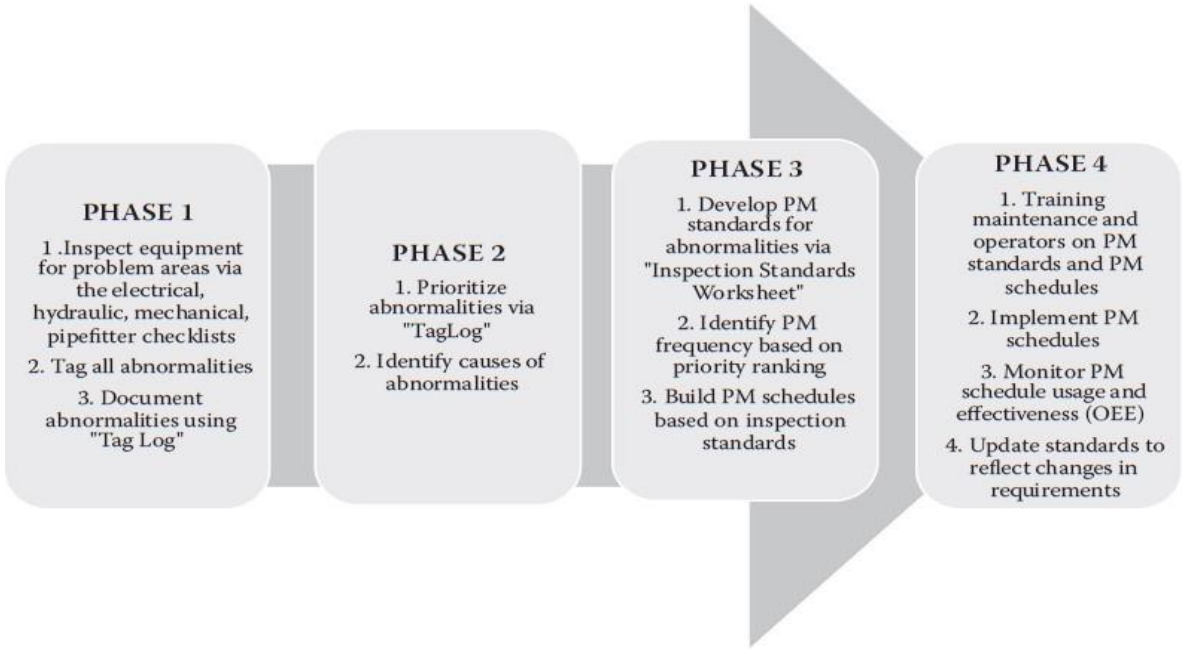


Fig. 1. Four-phase preventive maintenance approach [5]

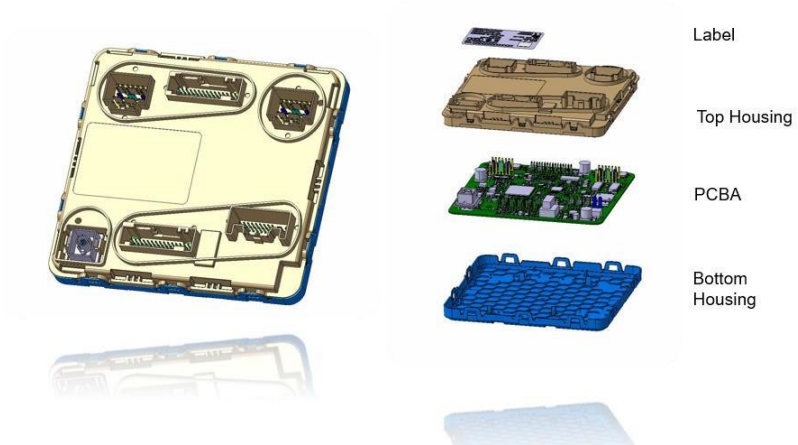


Fig. 2. Body Control Unit

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3.2 Presentation of BCM modules

The product that is assembled in the said production line is an electronic control unit. ECU (electronic control unit) is responsible for monitoring and controlling various electronic accessories in the body of a vehicle.

Typically, in a car, the BCM (Fig. 2) controls the power windows, power mirrors, air conditioning, immobilizer, central locking. The BCM communicates with other on-board computers via the vehicle bus, and its main application is to control load drivers - actuating relays that, in turn, perform actions in the vehicle, such as locking the doors, turning on the signals (in older cars), or dimming the interior light.

The electronic control unit is responsible for monitoring and controlling various electronic accessories in a vehicle's body. If installed in the engine compartment, BCMs can control the headlights, turn signals, and windshield washer system. If installed in the rear, they can control the taillights, rear window wiper, and door lock assist. A BCM in a car allows a vehicle to use fewer wires and electronic modules, reducing the weight of the car, improving fuel economy and energy efficiency, and lowering manufacturing costs as well as the total cost of ownership. Related to the overall vehicle electronic architecture, BCMs provide maximum reliability and economy by reducing the number of connections and wiring required. [7], [8]

3.3 BCM product operation process

As mentioned above, the BCM is a multi-faceted electronic unit that controls certain comfort and safety features in a car: windows, mirrors, temperature, wipers, etc. and supports multiple functions, the main one being the management of a range of electronic body components.

The BCM consists of both a hardware and a software part:

When it comes to hardware, the BCM has two types:

- Input devices: represent all sensors that transmit data to the BCM.
- Output devices: these generate a response to signals received from input devices.

For example, a person presses the power window switch and an input signal reaches the BCM. This, in turn, sends an output response to the small motor that executes the command and lowers or raises the car window. As a result, the window opens. Although the process involves several steps, a simple exchange like this takes less than a second [9].

When it comes to software, it hosts a multitude of algorithms, being a complex system that must consider a lot of variables. It generally connects to other components of the BCM with an API (application programming interface). An API is a way for two or more components to communicate with each other. The software must also comply with standards (ISO, AUTOSAR, SPICE). [9]

For example, if a person wants to unlock their vehicle with a remote key, the encrypted signal from the key is tied to a specific car. When the vehicle sensor detects it, the code is subjected to a decryption algorithm, and the doors are unlocked.

At the same time, the BCM software is responsible for calculating the current/total distance traveled, calculating and monitoring fuel consumption, deciding the most appropriate gear for the current speed, and displaying this information to the driver [9].

3.4 BCM problems and improvement solutions

In general, a vehicle's body control module facilitates the functions of the wipers, lighting, air conditioning, heating, and the anti-theft system. The BCM is also responsible for communicating with the vehicle's other control modules. This communication allows for simplified integration of a vehicle's vital systems for more efficient operation [10].

A BCM is typically located under the dashboard. This location tends to be standardized, with typical BCMs located near this area. However, the location of the BCM varies from one vehicle model to another. In some cases, partial disassembly of the dashboard is required to access the BCM [10].

There are several possible causes for the BCM to fail. The most common are the following:

- The BCM is electrocuted in an accident shaken violently by the shock, it can be destroyed, the wiring harness can be pulled out - one or more wires can come out, and if a single bare wire touches another wire or touches a metal part of the vehicle, then it will cause a short circuit.
- Excessive heating of the vehicle engine: this cause can damage the BCM or melt the insulation of the wiring.
- A flooded BCM will most likely fail. If the sensors are clogged with water, the BCM will not be able to execute the command, such as remotely opening the door locks, etc.
- Excessive vibration can cause the BCM to wear out. For example, an unbalanced tire can vibrate the vehicle. And simple wear will eventually lead to the failure of the BCM [11].

The BCM rarely presents serious operational problems or total damage, which is why there are several signs associated with BCM failure, with some of these symptoms tending to be more prevalent than others. [10]

1. Repeated battery drain

The most common symptom of a BCM failure is repeated battery drain, also known as parasitic drain. Excessive battery drain is a sign of BCM damage, and it occurs when a BCM continues to supply power to a specific part/accessory at incorrect times.

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2. Erratic electrical function

A BCM failure can cause various electrical functions, such as a vehicle's horn, lights, and wipers, to operate intermittently. Another sign of failure can be the instrument cluster's sweeping dials and erratic door lock and radio functionality. Such problems are more likely to be BCM-related when several of these symptoms are present at the same time.

3. Security system problems

The BCM generally operates the security system of a vehicle. So, it is easy to assume that if there are consistent issues with a vehicle's security system, it is a result of a faulty body control module. This can also include issues with keyless entry functions.

4. Dash warning lights

Another sign of a BCM failure is when the dash appears to have a dash and starts to resemble a Christmas tree. This occurs when a BCM can no longer communicate with one of the additional control modules of a vehicle, such as the transmission control module, powertrain control module, or airbag control module.

5. Failure to start

A faulty body control module can also prevent a vehicle from starting in some cases. The lack of communication between the BCM and other control modules can lead to starting difficulties when a faulty BCM fails to identify the key's transponder chip or simply cannot provide a "start" signal from a vehicle's ignition switch. [10]

Next, we will present some solutions to the challenges faced by BCM:

- Regarding battery life, from a software perspective, competent architecture design can prevent the system from being overloaded and using more power than necessary. From a hardware perspective, consider using quad flat packages when building a more cost-effective BCM.
- Regarding performance, processing speed, but also response times, depend a lot on the architecture. It is certain that sometimes the performance of the software proves the skills of the developer. An industry-resistant application architecture is a huge advantage. To give the BCM more speed, separate processors for inputs and outputs can be equipped.
- Another solution is the increasing complexity, namely the number of input and output channels that the BCM must connect to. This varies from car to car. As vehicles become smarter and more powerful, the number of sensors and processors that BCM must deal with will also increase. There are two solutions to this. First, eSwitches with an SPI can help manage PWM channels when a lot of inputs and outputs are involved. Second, rapid prototyping for BCMs can help deliver more complex modules in shorter cycles [10].

Steps for the diagnostic and repair procedure:

1. Locate the BCM using the appropriate workshop manual for your vehicle.
2. Determine the problem by observing what is not working (example: door locks). Check fuses and relays for malfunction. Then check the wiring connections. Carefully rotate the connector to ensure it is not dangling. Check the individual pins for looseness.
3. Check for power at each terminal. Use the BCM diagnostic code reader to determine which pin or pins are having problems. If any of the terminals are not receiving power, the problem is most likely in the wiring. If power is being applied to the terminals, then the problem is in the BCM itself.
4. Before replacing the BCM, it is recommended to consult with your dealer or preferred technician.

It is important to note that only a portion of the BCM can be damaged; so the remote control may work, but the power door locks will not work [11].

It is possible to drive with a damaged BCM, but it is not recommended. However, in some situations a BCM can be reset to restore full functionality. This, of course, depends on the internal circuitry of a module being in proper working order, as no reset will fix compromised internal electrical circuitry. The procedure for resetting a BCM generally differs from one make and model of vehicle to another. In many cases, this is done by disconnecting a vehicle's battery, while other vehicles require a specialized fuse to remove.

In the event of a BCM failure, the cost of replacing the body control module varies from one vehicle make and model to another. However, the average cost of replacing a BCM ranges from 1,300 RON to 2,800 RON. The largest variable in this price is the actual cost of the failed module itself. Currently, the transportation costs associated with locating and procuring such modules can also affect the outcome of these repairs, as module availability has become somewhat of an issue [10].

3.5 Application of TPM on BCM in the analyzed company - Maintenance Plan

In the following table we will describe the individual maintenance plan for each process of the analyzed company in western Romania. A rule valid for each process is the first step, namely: check the safety elements: emergency stop buttons, optical barriers, sensors, protective doors, scanners and other protective elements of the machine and test their functionality, and where necessary, check the entire compressed air installation for air leaks and fix any defects (connections, hoses, regulators, cylinders, decanters, control islands and valves).

Next, we will present in tabular form (Table 1), the individual maintenance plan in steps, both monthly and every three months, where necessary.

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Table 1. Maintenance plan of the analyzed company

Process/ Equipment	Maintenance type	Main activities
A.Selective soldering	Monthly	Linear bearing lubrication; check for flux, nitrogen, air leaks; container pressure; cylinder adjustment; check solder level; cabin filter
	Once every 3 months	Cleaning ionizer nozzles
B.Pin Insertion	Monthly	Greasing the slide and bearing rail (NLGI 3); cleaning + greasing the pneumatic guide; greasing the cams, rollers, mechanisms (NLGI 000/00); checking sensors, clamping systems, control panel
	Once every 3 months	Checking transmission, running rails, ball cages, springs; cleaning bearings; checking belts, knives and dies
C.Milling	Monthly	Cleaning + lubricating X,Y axes; emptying pneumatic condensers; checking air filters
	Once every 3 months	Cleaning particle system nozzles
D.Circuit Testing	Monthly	Machine cleaning, electrical + mechanical visual checks; corrosion inspection
	Once every 3 months	Check pneumatic connectors, sensor positions, functionality
E.Case assembly	Monthly	PCB glass cleaning, vacuum cups, emergency buttons, light; dust extraction; capacitor emptying
	Once every 3 months	Lubricate the vertical axes of the press with NLGI 2 grease; wipe off excess.
F.Radio Frequency Testing	Monthly	Blower cleaning, coupling/socket check, power unit cleaning
G. Kessy Testing	Monthly	Blower cleaning, coupling/socket check, power unit cleaning
	Once every 3 months	Cleaning ionizer nozzles
H.End of Line	Monthly	Technician announcement, test pin check
	Once every 3 months	Checking the pneumatic circuit, filters, bearings and lubrication
I.Automatic optical inspection	Monthly	Backup engineer announcement; tightening lens screws
J.Immobilization process	Monthly	Cleaning fan guard; cleaning/changing electrical panel filters
K.Logistics Box	Monthly	Checking and changing electrical panel filters

IV. RESEARCH RESULTS AND LIMITATIONS

The implementation of TPM led to a 30% reduction in the average downtime of equipment involved in BCM testing, as well as an increase in the meantime between failures. However, the analysis was limited by the lack of complete data series on BCM failure history, as well as the difficulty in accurately measuring the influence of autonomous maintenance outside of standard TPM components.

The originality of the presented research lies in the practical application of a well-established Japanese model (TPM) in the context of a Romanian company in the automotive industry, on a complex electronic module such as the BCM. Most studies on TPM focus on mechanical equipment or standard production lines; instead, this work extends the applicability of TPM to sensitive electronic components, thus contributing to the development of good maintenance practices adapted to new technological realities.

VI. CONCLUSIONS

The application of the Total Productive Maintenance (TPM) method to Body Control Module (BCM) modules highlighted the high potential of this approach in reducing downtime and increasing the reliability of electronic systems in the automotive industry. By integrating preventive maintenance and fault cause analysis, TPM contributes to optimizing maintenance processes and extending the life of components.

The case study demonstrated that, despite the increased complexity of BCMs, the rigorous implementation of a TPM program allows for the anticipation of critical problems, the reduction of unplanned costs and the improvement of the overall performance of the vehicle. At the same time, the paper highlighted the specific challenges, such as difficult access to the module or its architectural limitations, offering applicable and current solutions.

The main contribution of the research consists in providing an applicable model of intelligent maintenance for complex electronic components, supported by good technical and analytical practices.

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