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# Sustainability Through Maintenance in Transportation Area

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***Abstract*— Now a days transportation industries are reaching its peak, so the current challenge is to sustain the results and hold the market values. For achieving the sustainability in market, maintenance will give a good hold to grow.**

**It is essential to keep the vehicle in appropriate condition for compelling running, longer life and mishap anticipation. On the off chance that the issue in a vehicle isn't detected well before, then efficient running isn't conceivable. Thus, vehicle condition checking framework through dashboard is executed which shows the precise condition of the vehicle in case these conditions are not addresses in time, mileage of the vehicle will reduce; emission issue will emerge; this will lead to huge number of unscheduled emergency repairs, Over the top downtime & trouble of planning. And this will specifically affect the need of certainty of the client.**

**In setting up the preventive support framework, several variables are having to be considered is complexity of hardware, recurrence & conditions of utilization, history of disappointment recurrence. This paper will focus on to get it over the challenges, fault diagnostics, predictive upkeep, and preventive support, will also give statistical induction of diverse strategies utilized for support. This paper will also present anticipated results, hurdles, and openings of these approaches.**

## I. INTRODUCTION

Preventive maintenance is the kind of upkeep done on machinery or equipment before it malfunctions or breaks down. Preventive maintenance's objective is to decrease the possibility of equipment failure and increase the equipment's lifespan. Generally, preventive maintenance is planned on a daily, weekly, monthly, or annual basis. Inspections, cleaning, lubrication, adjustments, and repairs are just a few examples of the various forms of preventive maintenance. The kind of equipment and how it is used determines the precise preventative maintenance procedures that are carried out. As an illustration, a manufacturing facility may carry out preventive maintenance on its production line by routinely checking and cleaning the machinery, lubricating moving parts, and modifying any subpar parts.

The kind of equipment and how it is used determines the precise preventative maintenance procedures that are carried out.[3,4,8] As an illustration, a manufacturing facility may carry out preventive maintenance on its production line by routinely checking and cleaning the machinery, lubricating moving parts, and modifying any subpar parts. Preventive maintenance can be carried on running vehicles by service center by regularly inspecting and calibrating its moving equipment to make sure it is functioning properly. Either internal employees or professional contractors can carry out preventive maintenance. The equipment manufacturer may occasionally offer recommendations for the frequency and methods of preventive maintenance tasks.

Along with managing and scheduling preventative maintenance chores, there are several software tools and systems available for tracking the equipment's history and condition. Improved safety, decreased maintenance costs, decreased downtime, and increased equipment reliability are just a few advantages of preventive maintenance. Preventive maintenance can save businesses money on repairs and lost productivity by identifying and fixing issues before they lead to equipment failure. In addition to helping businesses satisfy legal requirements, preventive maintenance can raise consumer satisfaction. For instance, to eliminate service interruptions and preserve customer satisfaction, a business that offers essential services like water or electricity may rely on preventive maintenance to make sure that its equipment is dependable and available when needed.

## II. TERMS OF MAINTENANCE

Table 1: Terms of Maintenance [8]

| | |
|---|---|
| Maintenance | Preventive Maintenance |
| | Predictive Maintenance |
| | Condition based Maintenance |
| | Reactive Maintenance |
| | Time triggered maintenance |
| | Maintenance |
| | Prescriptive Maintenance |
| | Time based maintenance |
| Maintenance of Electric/ Electronic System | Electrical System Maintenance |
| | Electrical System Diagnosis |
| | Electronic System Diagnostic |
| | Electronic Fault |
| | Electrical Diagnostic |
| | Electronic Maintenance |

| | |
|---|---|
| Vehicle fault | Prognostic |
| | Diagnostic |
| | fault |
| | Fault tolerant |
| | Fault Diagnostic |
| | Fault Management |
| | Fault Prognostic |
| | Failure Mode |
| | Failure |
| | Wear |
| | Tear |
| Risk Analysis | Risk Management |
| | Maintenance optimization |
| | Potential loss of life (PLL) |
| | Fatal Accident Rate (FAR) |
| | Event tree Analysis |
| | Fault tree analysis |
| | Failure mode and effect and criticality analysis (FMECA) |
| | Hazard and operability study (HAZOP) |
| | FMEA |
| | Reliability Centered Maintenance (RCM) |
| | Safety |
| | FTA |
| | Vehicle Health Management |
| Maintenance for Automotive Industry | Vehicle Health |
| | Vehicle Diagnostic |
| | Vehicle Prognostics |
| | Vehicle Fault |
| | Autonomous System maintenance |
| | ADS Maintenance |
| | ADS |
| | ADAS |
| | Vehicle Maintenance |
| | Ground Vehicle Maintenance |
| | IVHM |
| Maintenance for Aerospace Industry | Airplane Maintenance |
| | Airplane Health Management |
| | Aeroplan Maintenance |
| | Aeroplan Health Management |
| | Airplane Fault |
| | Airplane Prognostic |
| | Airplane Diagnostic |
| | |

The table shows the globally used teams related to the maintenance and its description.

Maintenance Types

- Preventive Maintenance: Regularly scheduled maintenance to prevent equipment failure.
- Predictive Maintenance: Using data and analytics to predict when maintenance should be performed.
- Condition-based Maintenance: Maintenance based on the actual condition of equipment, rather than a set schedule.
- Reactive Maintenance: Fixing equipment after it has broken down.
- Time-triggered Maintenance: Maintenance performed at specific time intervals.
- Prescriptive Maintenance: Advanced maintenance strategy that uses data to prescribe specific actions to prevent failures.
- Time-based Maintenance: Similar to preventive maintenance, performed at regular intervals regardless of equipment condition.

Maintenance of Electric/Electronic Systems

- Electrical System Maintenance: Regular upkeep of electrical systems to ensure they function correctly.
- Electrical System Diagnosis: Identifying issues within electrical systems.
- Electronic System Diagnostic: Similar to electrical diagnosis but focused on electronic systems.
- Electronic Fault: Issues or malfunctions within electronic systems.
- Electrical Diagnostic: Testing and troubleshooting electrical systems.
- Electronic Maintenance: Regular upkeep of electronic systems to ensure they function correctly.

Vehicle Fault

- Prognostic: Predicting future faults based on current data.
- Diagnostic: Identifying and analyzing faults.
- Fault: Any malfunction or defect in the vehicle.
- Fault Tolerant: Systems designed to continue functioning despite faults.
- Fault Diagnostic: Techniques used to detect and diagnose faults.
- Fault Management: Strategies to handle and mitigate faults.
- Fault Prognostic: Predicting faults before they occur.
- Failure Mode: The ways in which a system can fail.
- Failure: The state of a system when it stops functioning correctly.
- Wear: Gradual deterioration of components over time.
- Tear: Damage caused by use or stress.

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Risk Analysis

- Risk Management: Identifying, assessing, and controlling risks.
- Maintenance Optimization: Improving maintenance processes to reduce risks and costs.
- Potential Loss of Life (PLL): Estimating the risk of fatalities.
- Fatal Accident Rate (FAR): The frequency of fatal accidents.
- Event Tree Analysis: A method to analyze the outcomes of different events.
- Fault Tree Analysis: A technique to identify the root causes of faults.
- Failure Mode and Effect and Criticality Analysis (FMECA): Assessing the impact of different failure modes.
- Hazard and Operability Study (HAZOP): Identifying potential hazards and operability issues.
- Failure Modes and Effects Analysis (FMEA): Systematic evaluation of potential failure modes.
- Reliability Centered Maintenance (RCM): Ensuring maintenance strategies enhance reliability.
- Safety: Measures to ensure the safety of systems and personnel.

Maintenance for Automotive Industry

- Vehicle Health Management: Monitoring and maintaining the overall health of vehicles.
- Vehicle Health: The current condition of a vehicle.
- Vehicle Diagnostic: Techniques to identify issues in vehicles.
- Vehicle Prognostics: Predicting future vehicle issues.
- Vehicle Fault: Any malfunction or defect in a vehicle.
- Autonomous System Maintenance: Maintenance of self-driving systems.
- ADS Maintenance: Maintenance of Automated Driving Systems.
- ADS: Automated Driving Systems.
- ADAS: Advanced Driver Assistance Systems.
- Vehicle Maintenance: Regular upkeep of vehicles.
- Ground Vehicle Maintenance: Maintenance of vehicles used on the ground.

Maintenance for Aerospace Industry

- IVHM: Integrated Vehicle Health Management, monitoring the health of aerospace vehicles.
- Airplane Maintenance: Regular upkeep of airplanes.
- Airplane Health Management: Monitoring and maintaining the health of airplanes.
- Aeroplane Maintenance: Same as airplane maintenance.
- Aeroplane Health Management: Same as airplane health management.
- Airplane Fault: Any malfunction or defect in an airplane.
- Airplane Prognostic: Predicting future airplane issues.
- Airplane Diagnostic: Techniques to identify issues in airplanes.

## III. PERFORMANCE ANALYSIS

In vehicle systems, a wide range of parameters are typically monitored to ensure optimal performance, safety, and maintenance. Here are some common types of parameters:

1. Engine Performance:
- Engine Temperature: Monitoring the temperature to prevent overheating
- RPM (Revolutions Per Minute): Tracking engine speed to ensure it operates within safe limits
- Oil Pressure: Ensuring adequate lubrication of engine components

2. Fuel System:
- Fuel Consumption: Measuring fuel usage to optimize efficiency
- Fuel Pressure: Monitoring pressure to ensure proper fuel delivery

3. Transmission:
- Gear Position: Tracking the current gear to ensure smooth shifting
- Transmission Fluid Temperature: Preventing overheating and ensuring proper lubrication

4. Braking System:
- Brake Fluid Level: Ensuring sufficient fluid for effective braking
- Brake Pad Wear: Monitoring the condition of brake pads

5. Tyre Health:
- Tyre Pressure: Maintaining optimal pressure for safety and efficiency
- Tyre Temperature: Preventing overheating and ensuring proper performance

6. Electrical System:
- Battery Voltage: Ensuring the battery is charged and functioning properly
- Alternator Output: Monitoring the alternator to ensure it is charging the battery

7. Environmental Conditions:
- Ambient Temperature: Monitoring external temperature to adjust vehicle systems accordingly
- Humidity: Tracking humidity levels to prevent corrosion and electrical issues

8. Vehicle Dynamics:
- Speed: Monitoring vehicle speed for safety and performance
- Acceleration: Tracking acceleration to ensure smooth driving
- Steering Angle: Monitoring steering input for proper handling

These parameters are typically monitored using various sensors and data loggers, which provide real-time insights into the vehicle's condition and performance

### A. How is sustainability achieved? :

The figure 1 depicts a flowchart illustrating a seven-step process for managing vehicle data and issues. Here's a breakdown of each step:

1. Data collection from vehicle: Gathering data from various sensors and systems within the vehicle.
2. Data analysis & integration with dashboard: Analyzing the collected data and integrating it into a dashboard for monitoring.
3. Issue detection: Identifying any problems or abnormalities in the vehicle's performance.

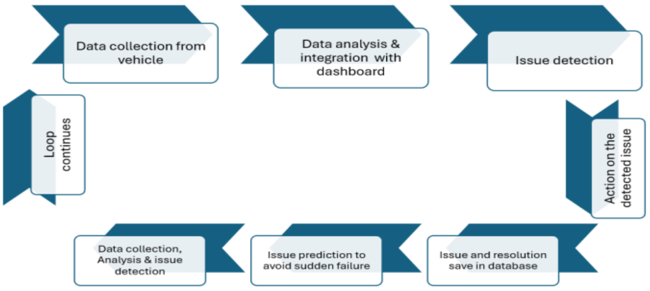


Figure 1: Sustainability achievement model

4. Action on the detected issue: Taking necessary actions to resolve the detected issues.
5. Issue and resolution save in database: Recording the issue and its resolution in a database for future reference.
6. Issue prediction to avoid sudden failure: Predicting potential issues to prevent unexpected failures.
7. Data collection, Analysis & issue detection: Continuously collecting and analyzing data to detect new issues.

The process forms a continuous loop to ensure ongoing monitoring and maintenance of the vehicle.

B. Primary causes of failure in vehicle:

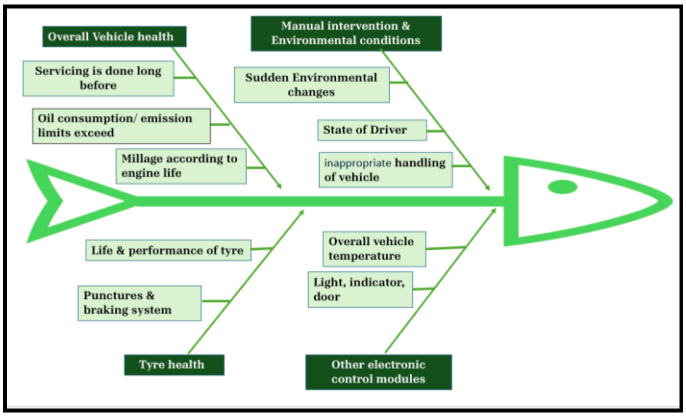


Figure 2: Primary causes of failure in vehicle

The Figure 2 is a fishbone diagram (also known as an Ishikawa diagram) used to identify potential causes of a problem related to vehicle health. Here's a breakdown of the categories and their potential causes:

1. Overall Vehicle Health:

There are some parameters which comes under the overall vehicle health umbrella:

1. Mechanical Problems:

- Engine Issues: Problems such as overheating, misfires, or lack of power can affect overall vehicle performance
- Transmission Failures: Difficulty in shifting gears or slipping gears can lead to significant vehicle health issues
- Brake System Failures: Worn brake pads, faulty brake lines, or malfunctioning ABS can compromise safety

2. Electrical System Failures:

- Battery Problems: A weak or dead battery can prevent the vehicle from starting
- Alternator Issues: A failing alternator can lead to electrical failures and battery drainage
- Faulty Wiring: Damaged or corroded wiring can cause intermittent electrical issues

3. Fluid Leaks:

- Oil Leaks: Leaks from the engine or transmission can lead to low fluid levels and potential damage
- Coolant Leaks: Leaks in the cooling system can cause overheating
- Brake Fluid Leaks: Leaks can lead to reduced braking efficiency

4. Suspension and Steering Issues:

- Worn Suspension Components: Worn shocks, struts, or bushings can affect ride quality and handling
- Steering Problems: Issues with the steering rack or power steering system can lead to difficulty in controlling the vehicle

2. Manual Intervention & Environmental Conditions:

Common causes of vehicle failure due to manual intervention and environmental conditions include:

1. Manual Intervention:

- Driver Error: Mistakes such as improper handling, sudden braking, or incorrect gear shifting can lead to vehicle issues
- Neglecting Maintenance: Failure to perform regular maintenance tasks like oil changes, brake checks, and tyre rotations can cause breakdowns
- Improper Repairs: Incorrectly performed repairs or use of substandard parts can lead to further issues

2. Environmental Conditions:

- Extreme Temperatures: High heat can cause overheating, while cold temperatures can affect battery performance and fluid viscosity
- Road Conditions: Poor road conditions, such as potholes, uneven surfaces, or debris, can cause damage to tyres, suspension, and other components
- Weather Conditions: Heavy rain, snow, or ice can impact vehicle handling and increase the risk of accidents
- Humidity: High humidity can lead to corrosion and electrical issues

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3. Tyre Health:

Common causes of tyre health issues include:

1. Uneven Tyre Wear:

- Improper Alignment: Misalignment causes tyres to wear unevenly as they do not meet the road surface at the correct angle.
- Incorrect Tyre Pressure: Both underinflation and overinflation can lead to uneven wear, affecting how the tyre's contact patch grips the road.
- Unbalanced Tyres: If tyres are not balanced, they can cause vibrations that lead to uneven wear over time.
- Suspension Issues: Worn or damaged suspension components can alter tyre alignment, leading to uneven wear patterns.
- Driving Habits: Aggressive driving, such as rapid acceleration and hard braking, can concentrate wear on specific tyre areas

2. Tyre Punctures:

- Road Debris: Nails, glass, and other sharp objects can penetrate the tyre.
- Potholes: Hitting potholes can cause punctures or internal tyre damage

3. Bald Tyres:

- Tread Wear: Driving on bald tyres significantly increases the risk of accidents, especially in adverse weather conditions

4. Tyre Blowouts:

- Overloading: Exceeding the vehicle's load capacity can lead to blowouts.
- Aged Tyres: Even if tread depth is adequate, tyres older than six years may be more prone to blowouts due to material degradation

5. Sidewall Damage:

- Impacts: Sudden impacts with road hazards can weaken tyre integrity over time

4. Overall Vehicle Temperature:

Common causes for overall vehicle temperature include:

1. Low Coolant Levels:

- Coolant Leaks: Leaks in the radiator, hoses, water pump, or heater core can lead to significant coolant loss
- Improperly Sealed Radiator Cap: A faulty radiator cap can cause coolant to escape

2. Thermostat Failure:

- Stuck Thermostat: If the thermostat is stuck in the closed position, coolant cannot circulate properly, causing the engine to overheat

3. Radiator Problems:

- Clogged Radiator: Debris, rust, or old coolant can block the radiator, reducing its efficiency
- Damaged Radiator Fins: Reduced airflow due to damaged fins can lead to overheating

4. Faulty Water Pump:

- Broken Water Pump: A malfunctioning water pump cannot circulate coolant effectively

5. Broken Fan:

- Non-Operational Fan: If the fan fails, especially while idling, it can cause the engine to overheat

6. Blown Head Gasket:

- Internal Coolant Leak: A blown head gasket can cause coolant to leak internally, leading to overheating

5. Light, Indicator, Door:

Common causes for light, indicator, and door failures in vehicles include:

1. Electrical Issues:

- Blown Fuses: Fuses protect electrical circuits; if they blow, the corresponding lights or indicators will stop working
- Faulty Wiring: Damaged or corroded wires can disrupt the electrical flow, causing lights and indicators to malfunction
- Battery Problems: A weak or dead battery can affect the operation of electrical components

2. Bulb Failures:

- Burnt-Out Bulbs: Over time, bulbs can burn out and need replacement
- Incorrect Bulb Type: Using the wrong type of bulb can lead to failures or improper functioning

3. Switch and Relay Issues:

- Faulty Switches: The switches that control lights and indicators can wear out or break
- Defective Relays: Relays help control the electrical flow; if they fail, the lights or indicators may not work

4. Door Mechanism Problems:

- Latch Issues: Worn or broken door latches can prevent doors from closing properly
- Sensor Failures: Modern vehicles often have sensors to detect if doors are closed; if these sensors fail, it can cause warning lights to stay on
- Hinges and Alignment: Misaligned doors or damaged hinges can affect the door's ability to close and seal properly

This Figure 2 helps in systematically identifying and analyzing the root causes of problems to improve vehicle maintenance and performance.

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C. Process flow for designing POC:

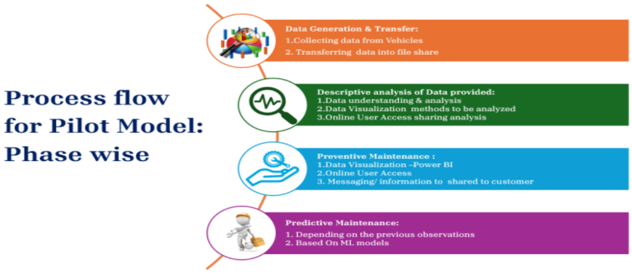


Figure 3: Process flow for designing POC

The figure 3 shows the phases of "Process flow for Pilot Model: Phase wise." It outlines four phases of a process:

1. Data Generation & Transfer:
- Collecting data from vehicles
- Transferring data into file share

2. Descriptive Analysis of Data Provided:
- Data understanding & analysis
- Data visualization methods to be analysed
- Online user access sharing analysis

There are different tools are available for data visualization, the tool can be decided depending on the objective of preject:

1. Tableau:
- Known for its robust data visualization capabilities and ease of use.
- Allows users to create interactive and shareable dashboards.
- Supports a wide range of data sources and offers extensive mapping features
2. Microsoft Power BI:
- Integrates well with other Microsoft products and services.
- Provides real-time analytics and interactive dashboards.
- Offers strong data security features
3. Qlik Sense:
- Focuses on self-service data visualization and discovery.
- Provides powerful associative data indexing and interactive visualizations
4. Looker:
- Offers data exploration and visualization capabilities.
- Integrates with various data sources and supports SQL-based queries
5. Zoho Analytics:
- Provides a comprehensive suite of data visualization tools.
- Supports collaboration and sharing of reports and dashboards
6. Domo:
- Known for its cloud-based business intelligence and data visualization.
- Offers real-time data integration and interactive dashboards

These tools help to turn raw data into meaningful insights through visually appealing charts, graphs, and dashboards.

3. Preventive Maintenance:
- Data visualization using Power BI
- Online user access
- Messaging/information to be shared with the customer

4. Predictive Maintenance:
- Based on previous observations
- Utilizing machine learning models

This figure represents a structured approach to managing vehicle data, from initial collection to predictive maintenance using advanced analytics.

D. Flowchart of Working principle:

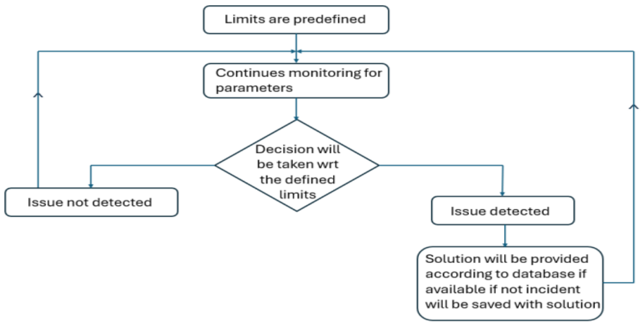


Figure 4:Flowchart of Working principle

Certainly! The decision-making process in the flowchart involves several key steps to ensure effective monitoring and resolution of issues. Here's a detailed explanation:

1. Limits are predefined:
- Before monitoring begins, acceptable limits for various parameters are established. These limits serve as benchmarks for evaluating the performance and health of the system.
2. Continuous monitoring for parameters:
- The system continuously observes the parameters to ensure they remain within the predefined limits. This ongoing monitoring helps in early detection of any deviations or anomalies.
3. Decision will be taken with respect to the defined limits:
- At this decision point, the monitored parameters are compared against the predefined limits. Based on this comparison, a decision is made:
- Issue not detected: If the parameters are within the acceptable limits, no issue is detected, and the process loops back to continue monitoring.
- Issue detected: If the parameters exceed the predefined limits, an issue is detected, and the process moves to the next step.
4. Solution will be provided according to the database if available:

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- If an issue is detected, the system checks the database for a predefined solution. If a solution is available, it is applied to resolve the issue.

5. If not, incident will be saved with solution:

- If no predefined solution is available in the database, the incident is recorded along with the solution provided. This helps in building a knowledge base for future reference and improving the decision-making process.

This structured approach ensures systematic monitoring, timely detection of issues, and effective resolution based on predefined limits and available solutions.

## IV. RESULT

the diffence after incorporating the preventive type of maintenance shows the remarkable result which are discussed below:

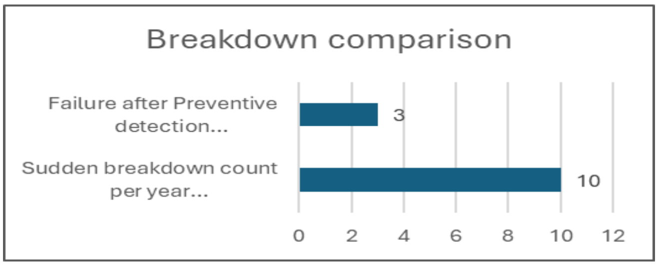


Figure 5:Breakdown comparison

The Figure 5 shows a "Breakdown Comparison." It compares two types of breakdowns:

1. Failure after Preventive Detection: This bar represents the number of failures that occurred even after preventive measures were taken, with a value of 3.
2. Sudden Breakdown Count per Year: This bar represents the number of sudden breakdowns that occurred within a year, with a value of 10.

The comparison, highlights that sudden breakdowns are more frequent compared to failures after preventive detection, emphasizing the importance of effective preventive maintenance to reduce unexpected issues.
For having the failure 0, after preventive maintenance need continuous following of system and global connectivity so that reference of another vehicle failure can be used solve the first time faced issue.

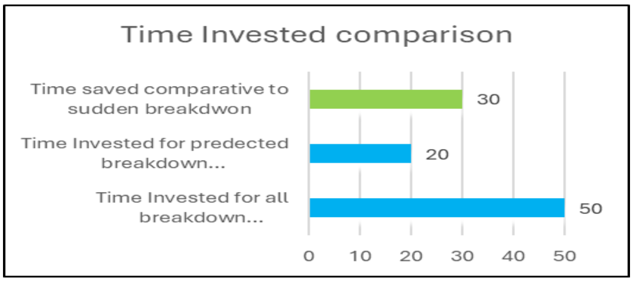


Figure 6:Time invested comparison

The figure 6 shows "Time Invested Comparison." It compares the time saved and invested in different breakdown scenarios:

1. Time Saved Comparative to Sudden Breakdown: This bar shows a value of 30 hours, indicating the amount of time saved by preventing sudden breakdowns.
2. Time Invested for Predicted Breakdown: This bar shows a value of 20 hours, representing the time spent on preventive measures for predicted breakdowns.
3. Time Invested for All Breakdowns: This bar shows a value of 50 hours, which includes the total time invested in handling all types of breakdowns.

The chart highlights that preventive maintenance can save significant time compared to dealing with sudden breakdowns, even though it requires an initial investment of time.

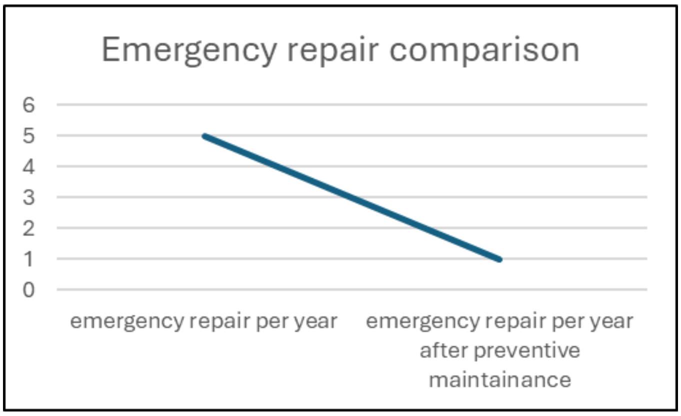


Figure 7:Emergency repair comparison

The Figure 7 shows "Emergency Repair Comparison." It compares the number of emergency repairs needed per year before and after implementing preventive maintenance.
The downward sloping line indicates that the number of emergency repairs significantly decreased after preventive maintenance was implemented. This highlights the effectiveness of preventive maintenance in reducing unexpected issues and improving the reliability of autonomous driving systems.

Optimizing preventive maintenance time for autonomous driving systems involves several strategies:

1. Implement Predictive Maintenance: Utilize AI and IoT technologies to predict when maintenance is needed based on real-time data, reducing unnecessary checks and focusing on actual needs
2. Automate Routine Tasks: Employ automated systems for routine inspections and diagnostics to save time and ensure consistency
3. Efficient Scheduling: Develop a well-organized maintenance schedule that prioritizes critical components and aligns with vehicle usage patterns
4. Use Advanced Analytics: Analyze historical data to identify patterns and optimize maintenance intervals, ensuring timely interventions without over-maintaining
5. Streamline Processes: Simplify maintenance procedures and ensure that all necessary tools and parts are readily available to minimize downtime

6. Training and Skill Development: Invest in training for maintenance personnel to enhance their efficiency and ability to handle complex tasks quickly
7. Regular Software Updates: Ensure that software updates are scheduled and applied efficiently to avoid disruptions and maintain system integrity

By implementing these strategies, significant reduction in time invested in preventive maintenance while maintaining the reliability and safety of autonomous driving systems is achieved.

## V. CONCLUSION

Preventive upkeep of autonomous driving systems is essential for guaranteeing secure and dependable functioning of these automobiles. Consistent inspections and updates assist in detecting and resolving potential problems before they escalate, thus reducing the likelihood of system breakdowns. This proactive strategy not only improves the lifespan but also the efficiency of autonomous vehicles and boosts overall road safety, building confidence in this cutting-edge technology of maintenance.

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