📄 P7.1 — What is Predictive Maintenance?

1. Introduction

Modern vehicle systems rely on distributed electronic control units (ECUs), sensors, and power electronics connected via deterministic communication networks such as CAN. Failures in these systems can be intermittent, silent, or progressive. Traditional “replace when failed” strategies are increasingly insufficient for safety-critical or uptime-critical applications.

Predictive Maintenance (PdM) introduces the ability to:

- **Detect degrading conditions**, not just failures
- **Warn in advance**, enabling planned service
- **Reduce cost**, downtime, and collateral damage
- **Provide context**, not just alerts

In this project, predictive maintenance focuses specifically on **wiring harness integrity**, where voltage drop and asymmetry between supply nodes reveal physical degradation (e.g., corrosion, resistance increase, partial open circuits).

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2. Maintenance Paradigms

Predictive maintenance sits between reactive and preventive approaches:

Paradigm	Trigger	Pros	Cons
Reactive	Failure occurs	Simple	Unexpected downtime, damage
Preventive	Time/usage schedule	Planned service	Wastes component life
Predictive	Condition-based	Optimized uptime, minimal waste	Requires sensing + logic

Our system implements **condition-based** predictive logic using live voltage measurements transmitted via CAN.

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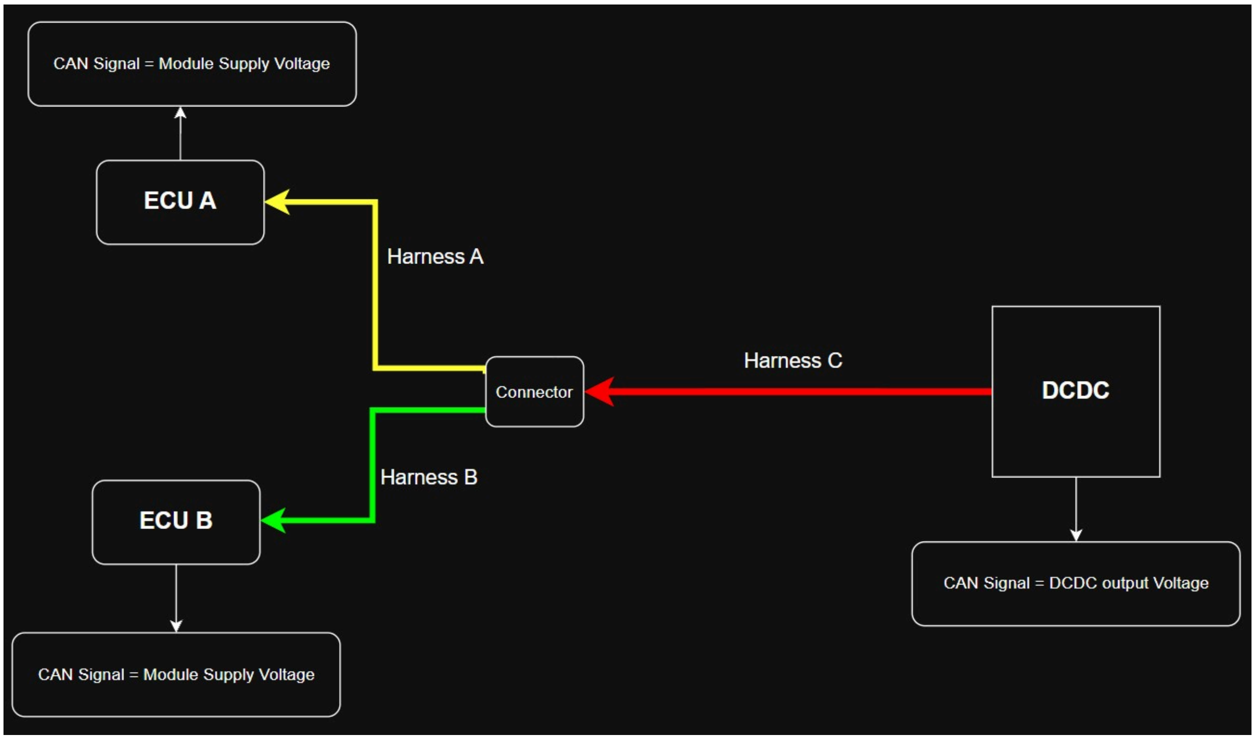
3. Why Predictive Maintenance on a Harness?

Here is the example for our demo



Wiring harness degradation is:

- Progressive
- Environmental (moisture, corrosion)
- Mechanical (vibration, strain)
- Thermal (resistance increases with temperature)
- Often silent until a failure event

Harness failures commonly manifest as:

- Voltage sags
- Voltage asymmetry between nodes
- Intermittent drop-outs
- Ground shifts
- Increased current draw
- Fault flags at ECUs

Physical measurements (e.g., mΩ) are not typically available to an embedded system, but **voltage comparison across nodes is**.

This aligns with our architecture:

> **ECU_A + ECU_B + DCDC** form three observation points of a single electrical network.

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4. Telematics + Condition Monitoring

The system being designed (Arduino UNO Q) acts as a **standalone telematics module** that:

- Listens passively on CAN
- Decodes ECU voltages via DBC
- Applies predictive logic
- Logs data for replay
- Raises alerts
- Stores evidence for service/diagnostics

This matches typical industrial PdM architectures used in:

- Rail rolling stock
- Mining vehicles
- Construction equipment
- EV fleets
- Marine power systems

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5. Measurable Indicators of Harness Degradation

The system uses several observable features:

Metric	Meaning
Absolute voltage	Global supply availability
Node-to-node delta	Wiring asymmetry
Delta vs DCDC	Harness loading behaviour
Drift over time	Progressive resistance
Recovery behaviour	Corrosion/contact phenomenon

These can detect early-stage issues long before a hard failure.

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6. Predictive vs Diagnostic Approaches

Traditional diagnostics rely on **fault codes** from ECUs (DTCs). These are binary and often late-stage.

Predictive maintenance uses:

- **Continuous measurements**
- **Tolerance windows**
- **Soft thresholds**
- **Temporal correlation**
- **Drift analysis**

This enables **"weak signal" detection** before any DTC is raised.

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7. Why CAN is a Good Medium

We deliberately placed logic on CAN rather than adding new sensors:

- CAN already carries analog telemetry (voltages)
- Telematics can eavesdrop without vehicle integration
- Zero changes to vehicle firmware
- Zero safety impact
- Works during operation
- Works across fleets

This minimizes integration and certification cost — extremely attractive to OEMs, Tier-1s, and fleet operators.

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8. Relation to Phase 7.2–7.4

Phase 7.1 sets the conceptual foundation for:

Phase	Meaning
7.2 Rule-based detection	Fast deterministic logic
7.3 Statistical anomaly detection	Drift + learning models
7.4 Edge vs Off-board trade-offs	Split processing for fleets

Rule-based logic gives **explainability**, statistical logic gives **resolution**, and fleet aggregation gives **confidence**.

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9. Summary

Predictive maintenance transforms maintenance from event-driven to condition-driven. For harness degradation, this is achieved through:

- Passive CAN observation
- Multi-node voltage sensing
- Real-time logic
- Offline replay
- Telemetry for fleets

Phase 7 turns the system from a **decoder and logger** into a **diagnostic and predictive instrument**.