CONFERENCE
OMAINTEC 2026
EXHIBITION FM

The 23rd International Asset Facility and Maintenance Management Conference

Sustainable Road Maintenance Optimization

Using Predictive Analytics, IoT, and Digital Twins Technology

12-14 January 2026

Riyadh, KSA

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Traditional Pavement Management

Current systems often rely on reactive interventions—fixing failures only after they occur. This leads to:

- **Suboptimal Resource Allocation:** Budget spent on emergencies rather than prevention.
- **Data Latency:** Annual surveys miss rapid deterioration events.
- **Environmental Impact:** High consumption of energy-intensive materials.

Climate change (heatwaves, freeze-thaw cycles) is drastically accelerating these deterioration rates.

Why Change?

Problem: Traditional Reactive Maintenance is Inefficient

High Cost: Suboptimal resource allocation, higher whole-lifecycle costs

Environmental Impact: Reliance on energy-intensive methods and virgin materials

Climate Urgency: Extreme heat and weather accelerate pavement deterioration

Goal: Shift to a Proactive, Prescriptive, and Sustainable Management System

What is The Digital Twiin?

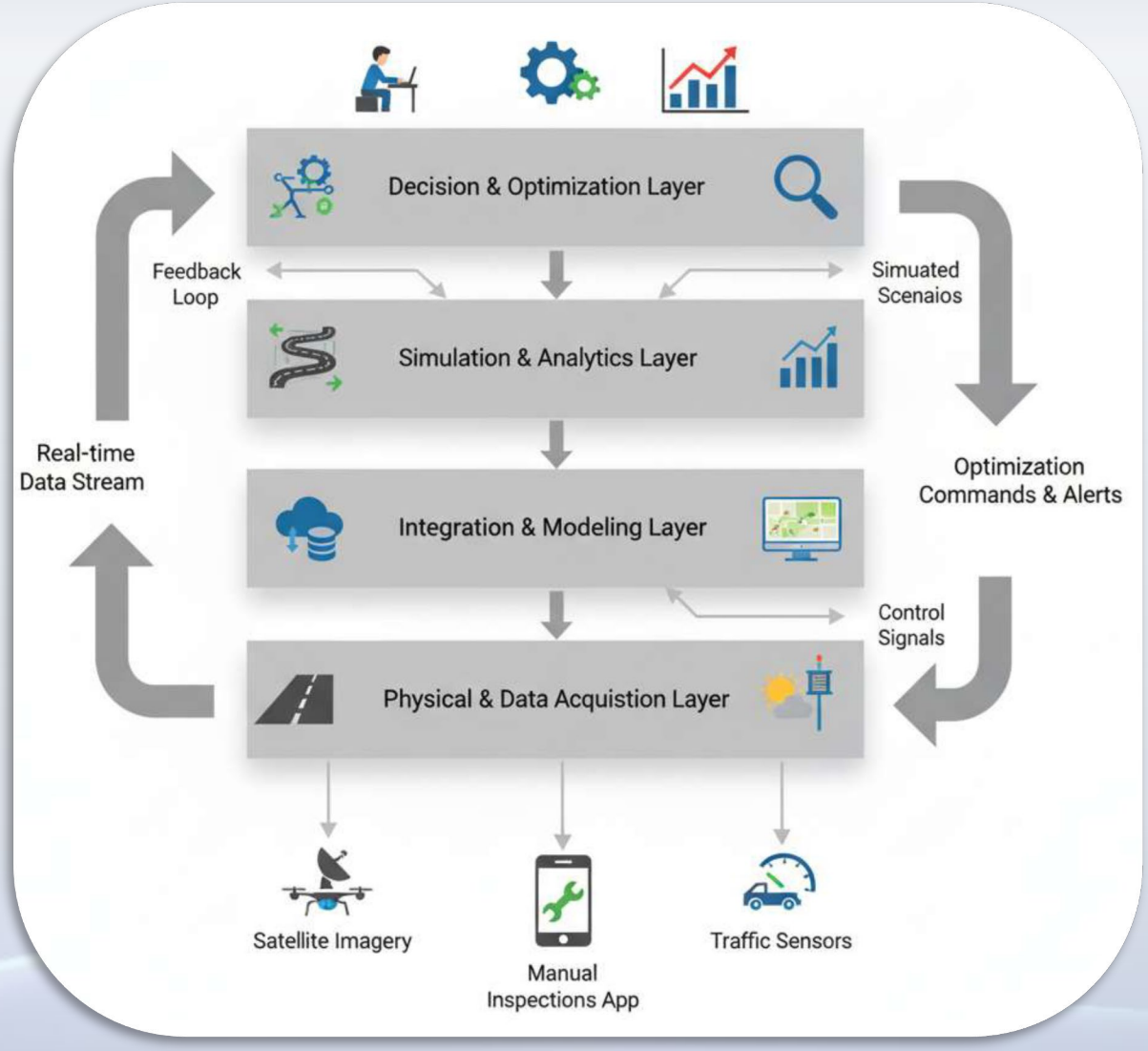
Definition: : A high-fidelity, dynamic, virtual replica of the physical road network

Function: Continuously updated with multi-source, real-time data to enable simulation, learning, and prescriptive action

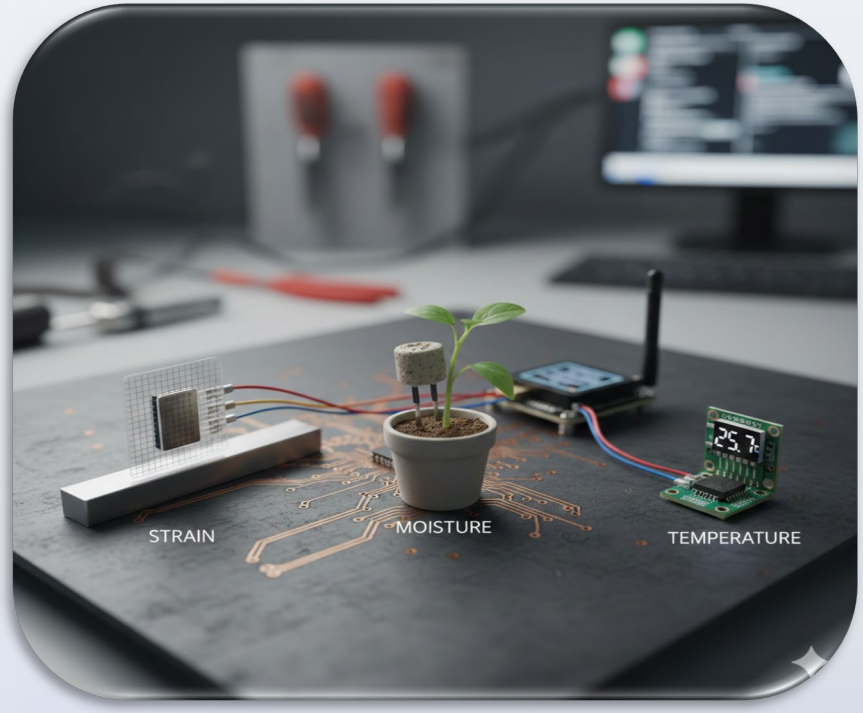
Pillars of the Framework

A Holistic, Integrated System

- **Physical & Data Acquisition:** The sensory nervous system
- **Integration & Modeling:** Creating the semantic Digital Twin
- **Simulation & Analytics:** The cognitive brain (Prediction/Prescription)
- **Decision & Optimization:** The actionable intelligence (Closed-loop)



Data Acquisition (The Sensory System)



Embedded IoT Sensors

Strain, Moisture, Temperature, Fiber Optics

Remote Sensing

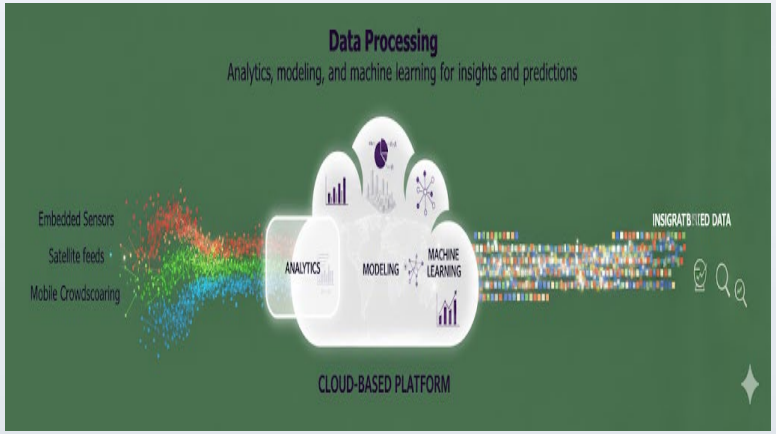
Satellite Imagery and Aerial Drone Photogrammetry/LiDAR

Data Acquisition (The Sensory System)

Mobile Crowdsourcing
Connected vehicles (IRI) and Dashcams

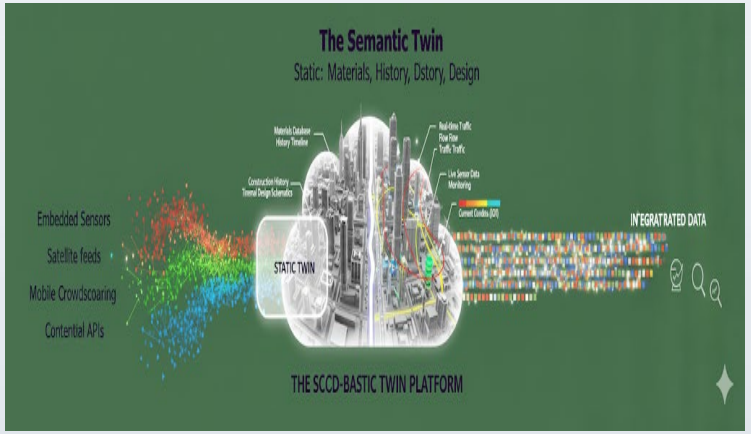
Contextual Feeds
Hyper-local Weather (Heat/Sandstorm modeling), Traffic, History

Integration & Modeling



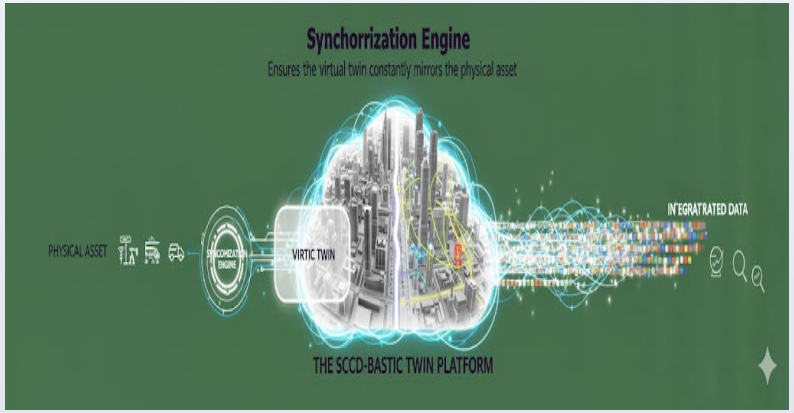
Data merge

Raw data cleaned, normalized, and geo-referenced in a cloud-based



The Semantic Twin

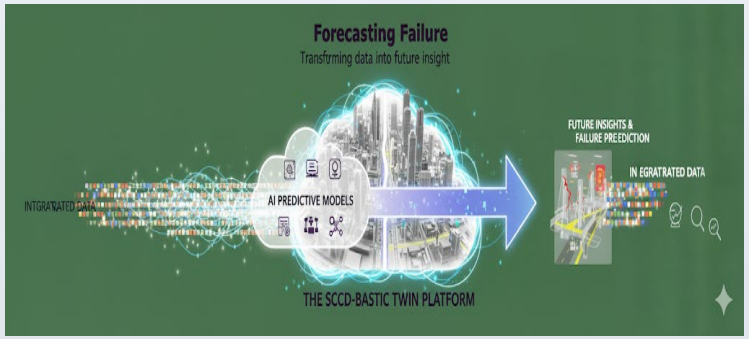
Static: Materials, History, Design
Dynamic: Real-time Sensors, Condition, Traffic

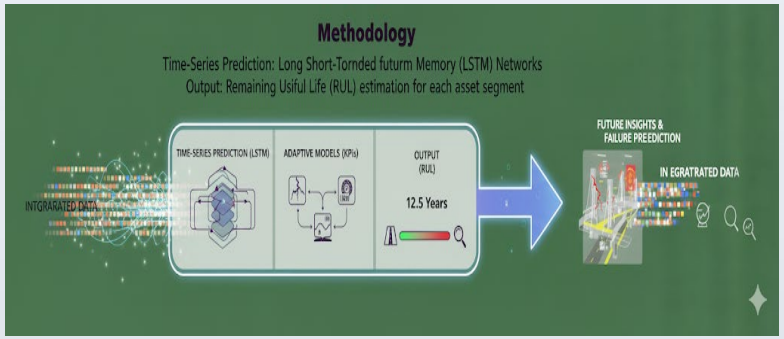


Synchronization Engine

Ensures the virtual twin constantly mirrors the physical asset

Predictive Analytics





Forecasting Failure

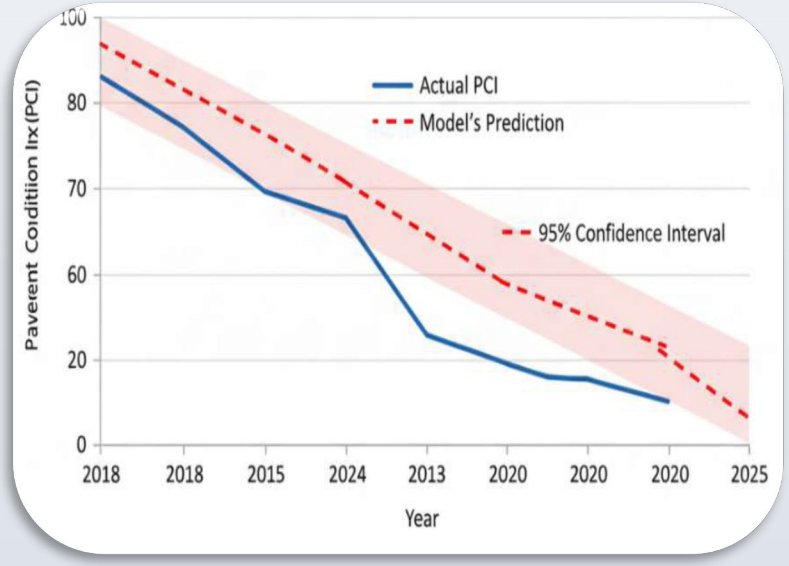
Transforming data into future insight

Methodology

Time-Series Prediction: Long Short-Term Memory (LSTM) Networks

Adaptive Models: Trained to predict future KPIs (IRI, cracking, rutting)

Output: Remaining Useful Life (RUL) estimation for each asset segment



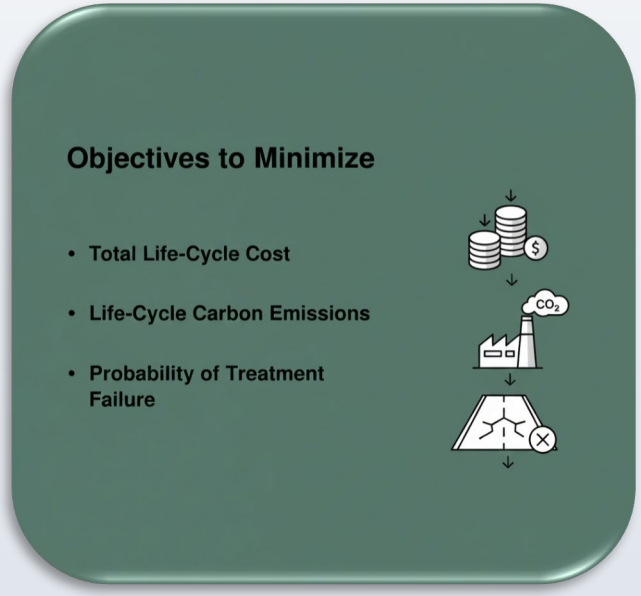
model's predictive accuracy

Prescriptive Analytics

Moving Beyond Prediction
System prescribes the **best** course of action

Engine
Multi-Objective Optimization (MOO) Algorithm

Ex.: Choosing Cold In-Place Recycling over Hot Mix Overlay reduces carbon by 60% while extending life by 12 years.



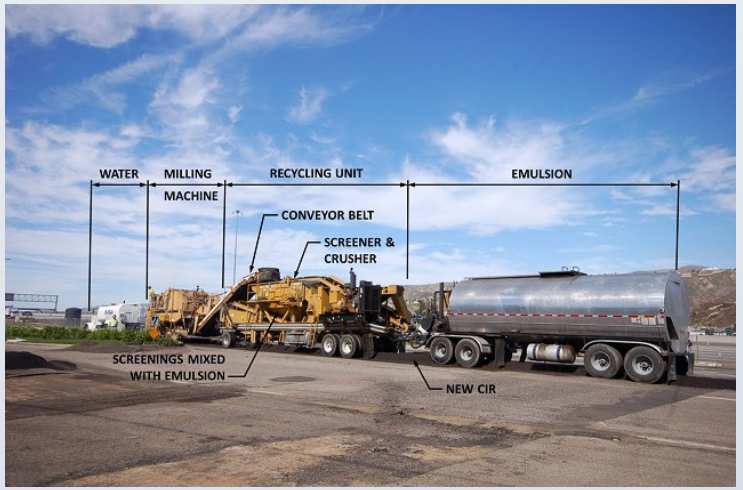
Objectives to Minimize
- Total Life-Cycle Cost
- Life-Cycle Carbon Emissions
- Probability of Treatment Failure

Sustainable Optimization: LCA Integration

Core Value: Sustainability is a primary optimization parameter

Life-Cycle Assessment (LCA): Embedded framework calculates environmental impacts of every material/process

- **Cradle-to-Gate**: Material extraction and manufacturing
- **Construction Phase**: Equipment fuel, traffic emissions
- **Use Phase**: Pavement roughness (IRI) on vehicle fuel economy
- **End-of-Life**: Recycling potential.



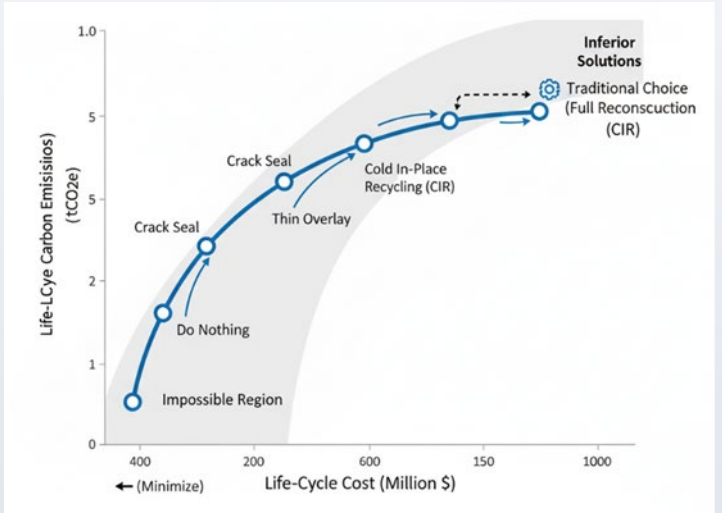
Case Study Simulation

- **Pareto-Optimal Solutions:** Identifies a set of non-dominated solutions

  Allows engineers to choose the option that best balances cost vs. carbon

- Cold In-Place Recycling (CIR) with a chip seal veneer is recommended: 25% cheaper and 60% carbon reduction vs. a hot-mix overlay

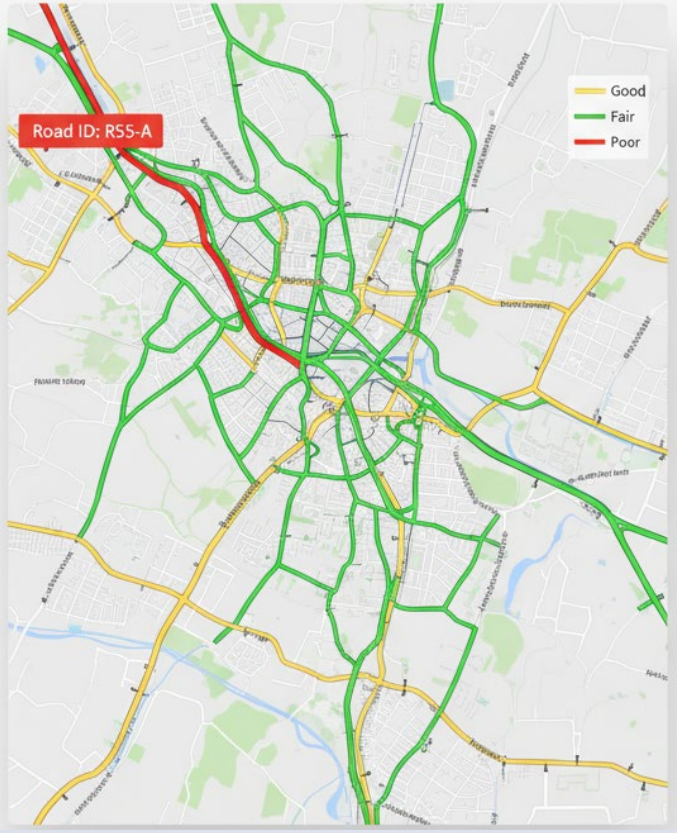
Average Network IRI improved by 14.3%, resulting in smoother, safer roads.



A Pareto front illustrating the trade-offs between cost and carbon emissions for various treatment options.

Visualization & Action

- **Interactive Dashboard:** Web-based GIS dashboard for visual network health
  - Color-coded segments by condition, risk, or recommended action
- **Drill-Down Capability:** View sensor data, predicted performance, and the sustainability scorecard for any segment
- **Closed-Loop Feedback:** Actual outcomes update the Digital Twin to continuously improve ML model accuracy



Conclusion

Summary

The Digital Twin approach transforms infrastructure management from reactive to proactive. It proves that economic efficiency and environmental responsibility are not mutually exclusive but synergistic.

Future Directions

- **Pilot Implementation:** Live deployment on a real-world network.
- **Advanced Physics Models:** Integrating material science for better accuracy.
- **Climate effect Optimization:** Better accounting for climate uncertainty.

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