WORKSHOP

Pavement operations & management

Monitoring, defect detection and engineering decisions

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60-minute workshop



PAVE-SENS concept illustration

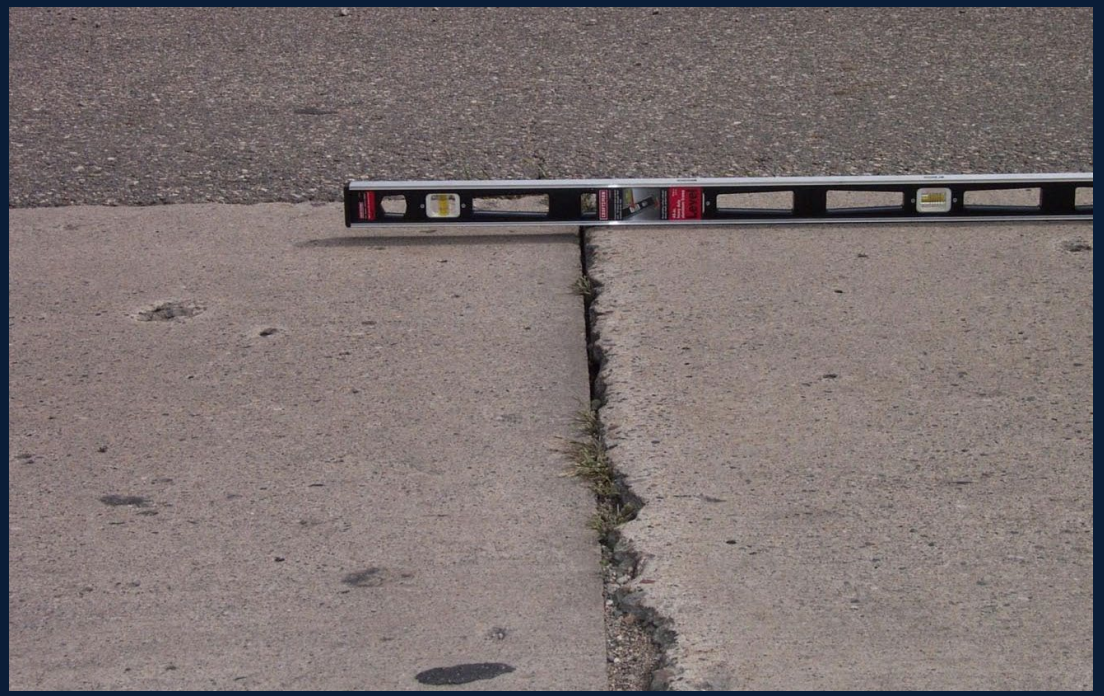
The workshop decision path

08 min	Pavement performance and monitoring needs
10 min	Defects and the evidence they require
08 min	Monitoring methods and data quality
16 min	Operations, treatment choices and a budget exercise
14 min	PAVE-SENS in the agency workflow
04 min	Takeaways and discussion

Which road needs attention first?



Widespread cracking



An abrupt joint level difference

What else do we need to know? Reference photographs: MnDOT

Road condition affects the transport service

Road users

Ride quality, hazard exposure and potential vehicle damage

Operators

Service reliability, route disruption and maintenance access

Asset owners

Lifecycle costs and the condition of the network

Environmental effects depend on materials, traffic and intervention choices

Deterioration has several interacting causes

Loading and support

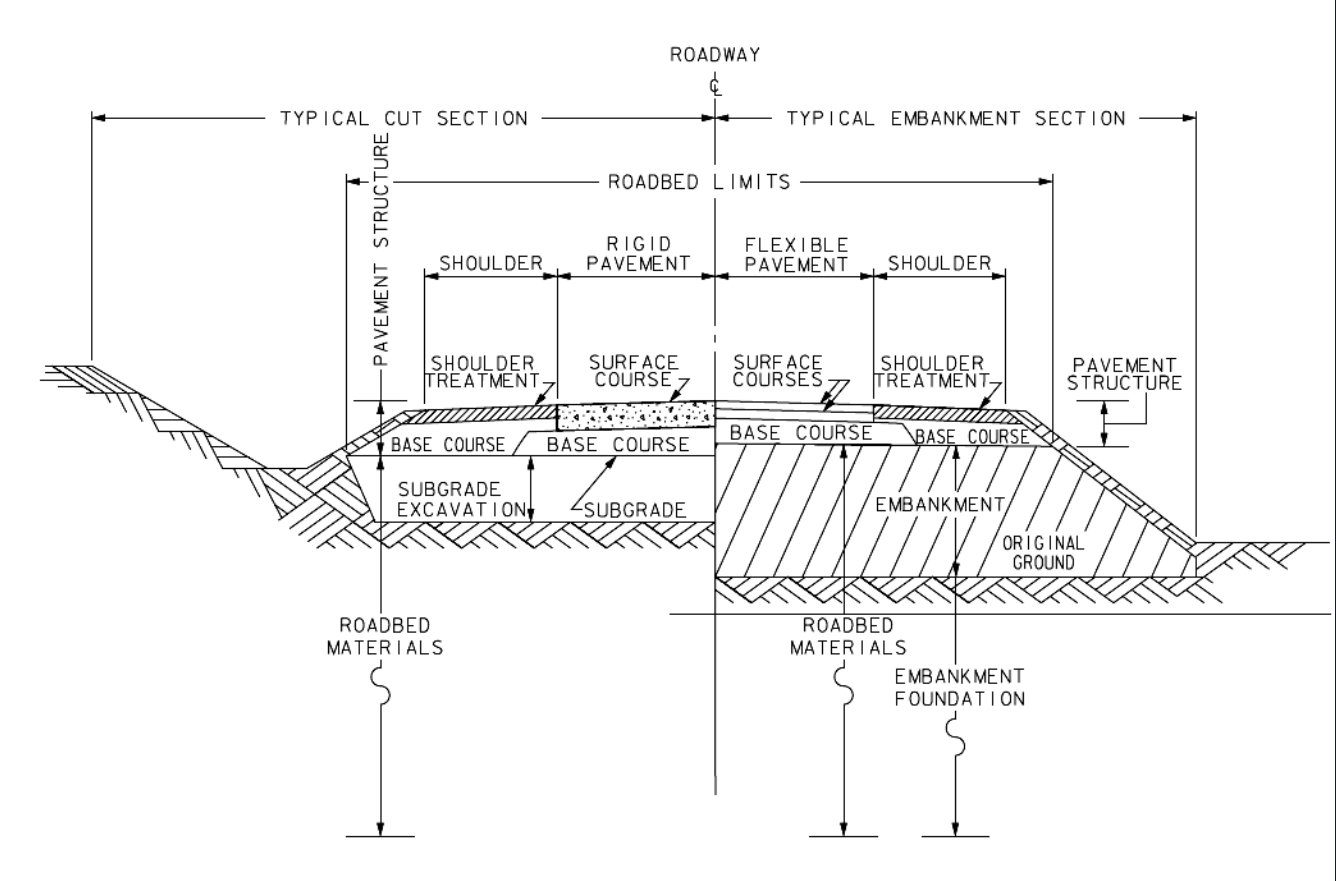
Repeated loading
Fatigue and permanent deformation
Foundation and material condition

Water, climate and time

Moisture infiltration
Thermal movement and ageing
Damage between treatments

Local materials, climate and traffic govern the engineering response

The surface is part of a pavement system



Surface

What we see and feel

Support

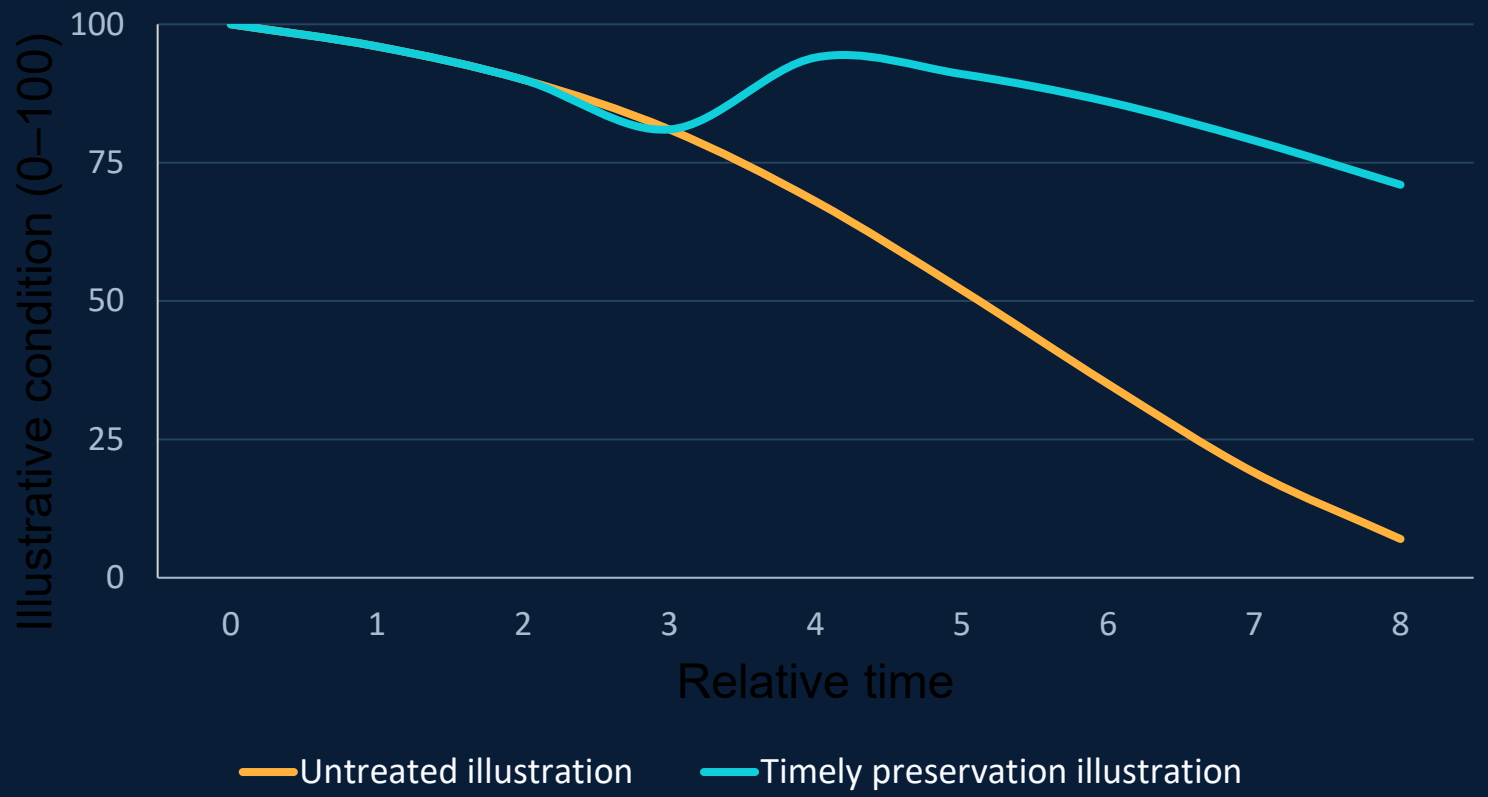
What carries the load

Drainage

What controls water

Reference cross-section: MnDOT Maintenance Manual, Figure 1

Preservation timing changes the future path



Candidate condition determines treatment suitability

Monitoring helps agencies recognise the window for action

Illustrative values and relative time only. No cost or service-life forecast

Four different monitoring questions

Question	Evidence needed
What distress is present?	Type, severity, extent and position
How does the road ride?	Longitudinal profile or a validated ride indicator
How does the surface perform?	Texture and friction investigation as appropriate
Can the structure carry the demand?	Deflection, layer information and engineering analysis

The monitoring specification should state the decision and the measurand

A useful distress record has context

Type

What is the observable defect?

Severity

How serious is it under the selected rating protocol?

Extent

How much pavement does it affect?

Every record also needs location, date, pavement type and supporting evidence

Crack patterns carry different information



Longitudinal



Block pattern



Alligator pattern

Describe the pattern before diagnosing the cause. Photographs: MnDOT

Severity changes the engineering question



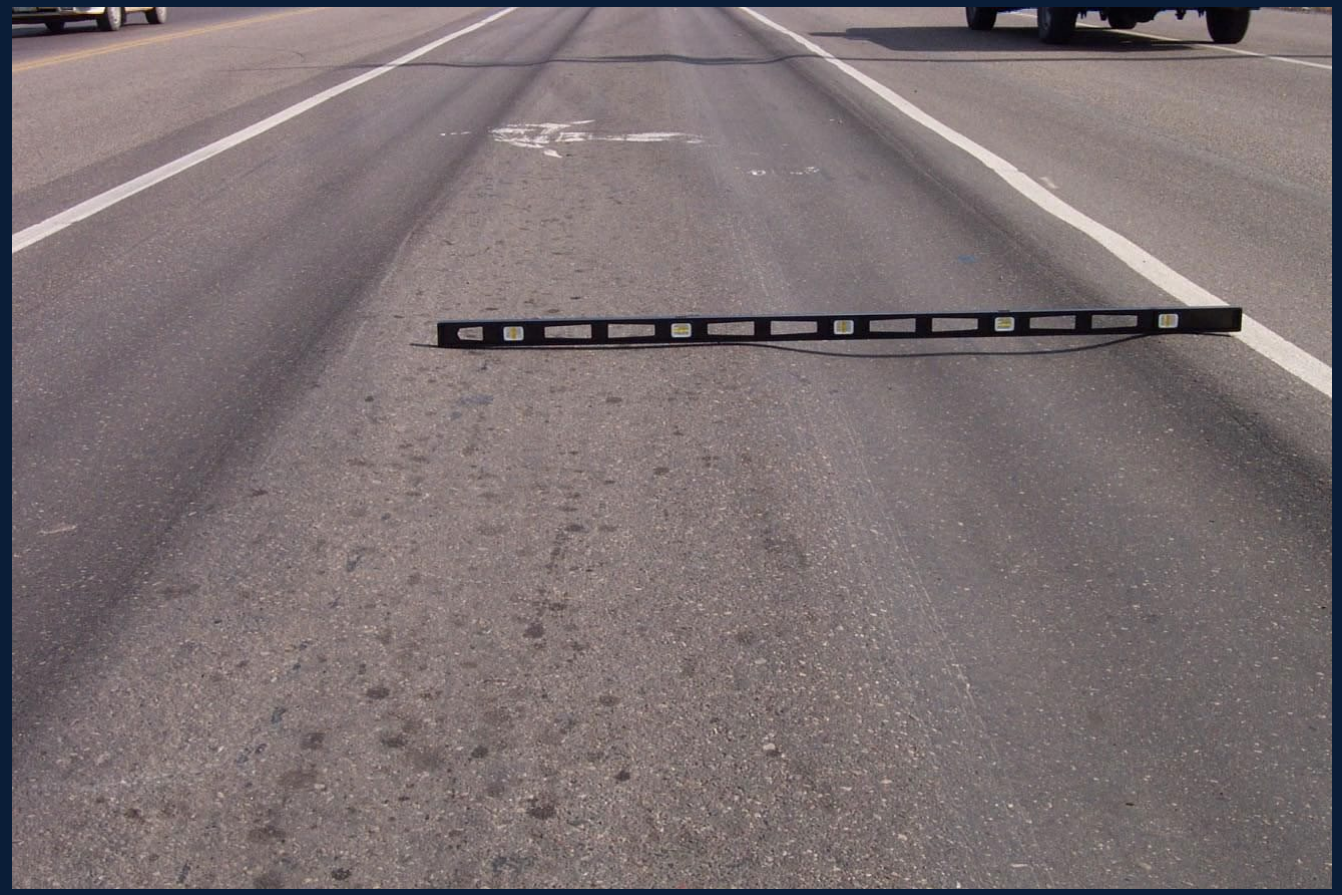
Low-severity example



High-severity example

MnDOT 2011 examples. Local rating rules must define severity consistently

Rutting needs a transverse measurement



Reference photograph: MnDOT. Vibration alone does not establish rut depth

Screening

Locate recurring deformation

Measurement

Establish rut depth

Diagnosis

Check the contributing layers

Material loss and repeated repairs



Pothole: operational exposure



Patch: repair history matters

Reference photographs: MnDOT Maintenance Manual and Distress Manual

Concrete needs its own distress taxonomy



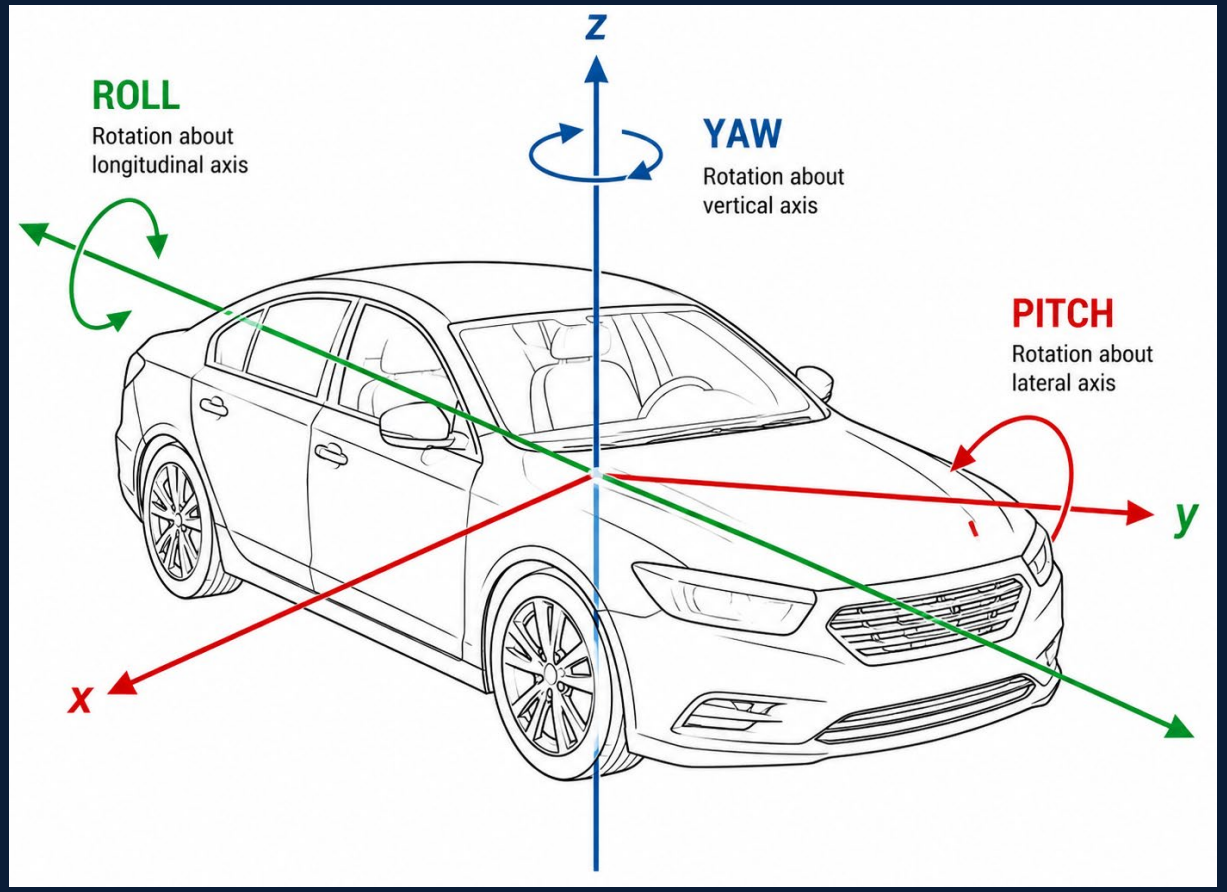
Joint spalling



Panel damage

Pavement type comes before the treatment rule. Reference photographs: MnDOT

The sensor measures a road–vehicle interaction



Vehicle context

Speed, suspension and mounting

Orientation

Roll, pitch and yaw

Corroboration

Repeat passes and imagery

Event detection and defect diagnosis are separate analytical tasks

Methods answer different monitoring questions

Method	Useful contribution	Key requirement
Field inspection	Context and defect verification	Consistent rating and safe access
Specialist profiling / imaging	Defined roughness and distress measures	Calibration and reference checks
Operational fleets	Repeated anomaly and condition observations	Vehicle context and validation
Targeted FWD / friction tests	Structural or surface-performance investigation	Decision-specific test programme

A combined programme connects screening, reference measurement and investigation

Coverage and recency belong on the map

Coverage

Which eligible road length has usable evidence?

Recency

How old is the latest accepted observation?

Support

How many independent passes and vehicles agree?

Unobserved roads need an explicit status

Quality assurance protects the decision

Acquisition controls

Mounting and sensor checks
Time and location alignment
Reference routes and repeat runs

Information controls

Completeness and anomaly review
Independent field checks
Error resolution and traceability

Reference practice: MnDOT Pavement Data Quality Management Plan (2018)

Condition indices serve different purposes

MnDOT reference	What it represents	2011 scale
RQI	Ride / smoothness	0–5, higher is better
SR	Surface distress	0–4, higher is better
PQI = √(RQI × SR)	Combined index	Approximately 0–4.5

PAVE-SENS classes 0–4 need a validated crosswalk before comparison

MnDOT 2011 definitions. Category labels and measurement scales are different

Network screening and project investigation

Network level

Where are recurring problems?
Which sections merit attention?
How do candidate programmes compare?

Project level

What causes the failure?
Which treatment fits the pavement?
What design and delivery checks apply?

Evidence becomes more specific as the decision becomes more consequential

The pavement management cycle

01 **Inventory and monitor**

Know the assets and condition evidence

02 **Assess and investigate**

Resolve uncertainty before choosing a treatment

03 **Programme and approve**

Select feasible packages within constraints

04 **Deliver and record**

Document work, location and resources

05 **Verify and learn**

Check the outcome and update the history

Different needs require different interventions

Family	Typical purpose	Example to investigate
Routine / local repair	Restore function or address an event	Pothole or localized patch repair
Preservation	Sustain a suitable pavement	Crack or surface treatment
Rehabilitation	Renew deteriorated pavement	Designed overlay or recycling
Reconstruction	Replace a failed pavement system	Renewal including support layers

Examples require project assessment and local treatment design

Treatment suitability comes before ranking

Observed need	Candidate response	Check first
Suitable cracks	Crack treatment	Movement, configuration and materials
Surface deterioration	Seal coat or micro-surfacing	Distress, friction and compatibility
Functional deterioration	Designed thin overlay	Support and pavement preparation
Recurring severe failure	Investigation / rehabilitation	Drainage, support and failure cause

Treatment examples for assessment. Eligibility comes before priority and budget

Urgent response has a separate decision path

Triage and verify

Confirm the location, exposure and urgency

Make safe and assign

Apply the agency procedure and nominate an owner

Repair and close

Record the intervention and verify the site before closure

Illustrative agency workflow. Local standards govern action and timing

Priority extends beyond the worst condition

Need and exposure

Severity, road role, traffic and affected services

Benefit and feasibility

Treatment suitability, expected performance and delivery constraints

Evidence and accountability

Confidence, verification needs and documented decisions

A condition ranking is an input to a programme, not a complete investment decision

Workshop exercise: a €100k programme

Package	Assumed action	Cost (€k)	Benefit points
A · mandatory	Immediate safety repair	20	Required
B	Preserve a suitable section	50	25
C	Targeted drainage and repairs	30	20
D · worst condition	Rehabilitate a deteriorated section	80	30

Which packages do you fund, and what evidence supports your choice?

Illustrative, indivisible packages. Benefit points are hypothetical and additive

Exercise debrief: allocation changes the result

Feasible allocation	Cost (€k)	Discretionary benefit
A + B + C	100	45 points
A + D	100	30 points

The highest-severity section does not automatically produce the best programme

Result depends on the stated eligibility, budget and benefit assumptions

The work record closes the information loop

Before work

Segment ID, evidence, treatment, approval and delivery constraints

During work

Actual extent, date, resources and changes to the scope

After work

Acceptance evidence, recurrence checks and updated asset history

Proposed agency record. Link through an agreed works-system integration

Sustainability needs lifecycle evidence

Potential mechanisms

Better intervention timing
Appropriate repair extent
Monitoring during existing journeys

Evidence to collect

Materials and repeat repairs
Travel and work-zone disruption
Lifecycle cost and environmental impact

Potential benefits require a defined baseline and measured outcomes

PAVE-SENS supports the information workflow

Routine fleet observations

Linked evidence for engineers

Condition maps and maintenance support



PAVE-SENS DSS concept artwork from the finalized conference presentation

Modular sensors on operational fleets

Acquire

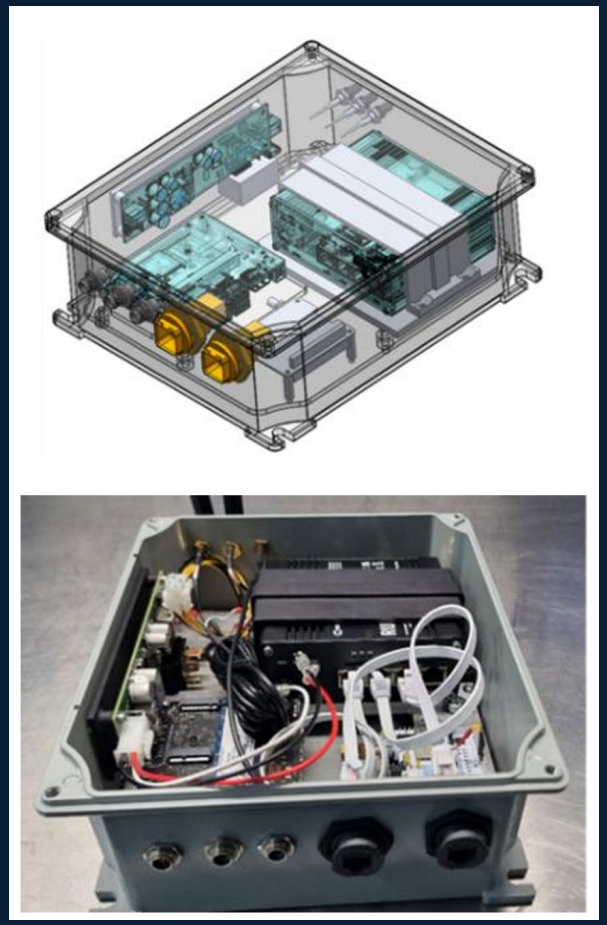
EGNSS, IMU and roadway imagery

Process and transmit

Synchronized edge and cloud workflow

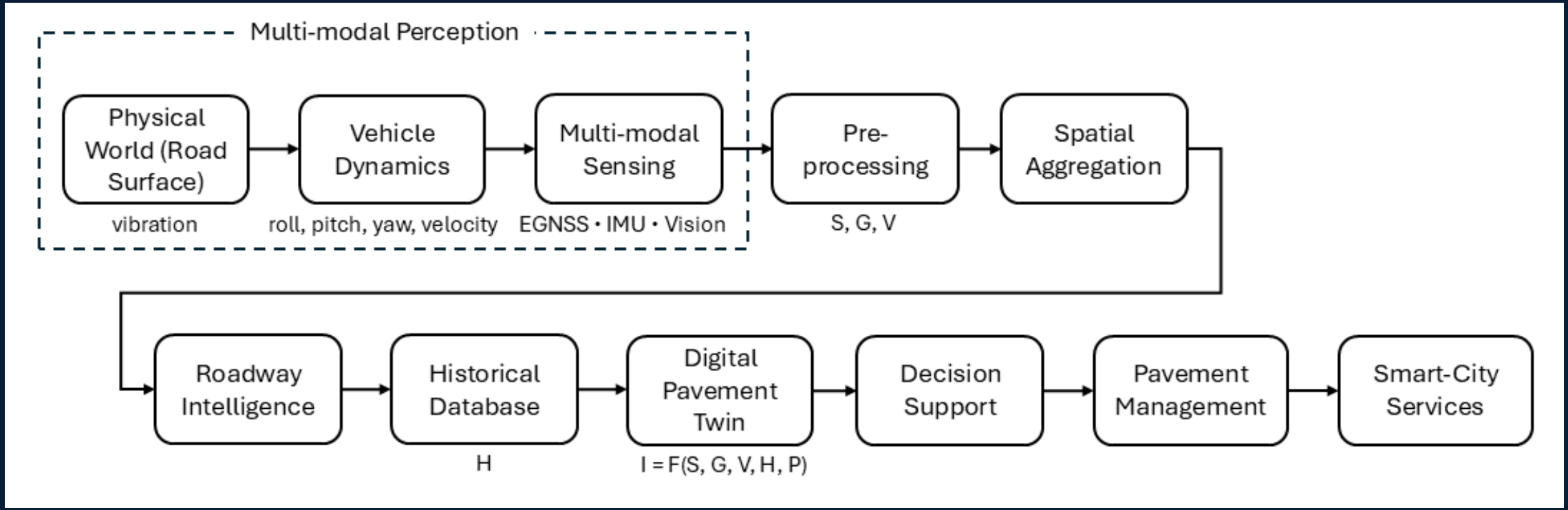
Deploy

Cars, municipal vehicles and buses



Configuration and positioning quality depend on the deployment

Evidence fusion creates a persistent road record



I = F(S, G, V, H, P)

Operational output: an evolving digital pavement representation

Nicosia demonstrates operational scale

≈2.5 million

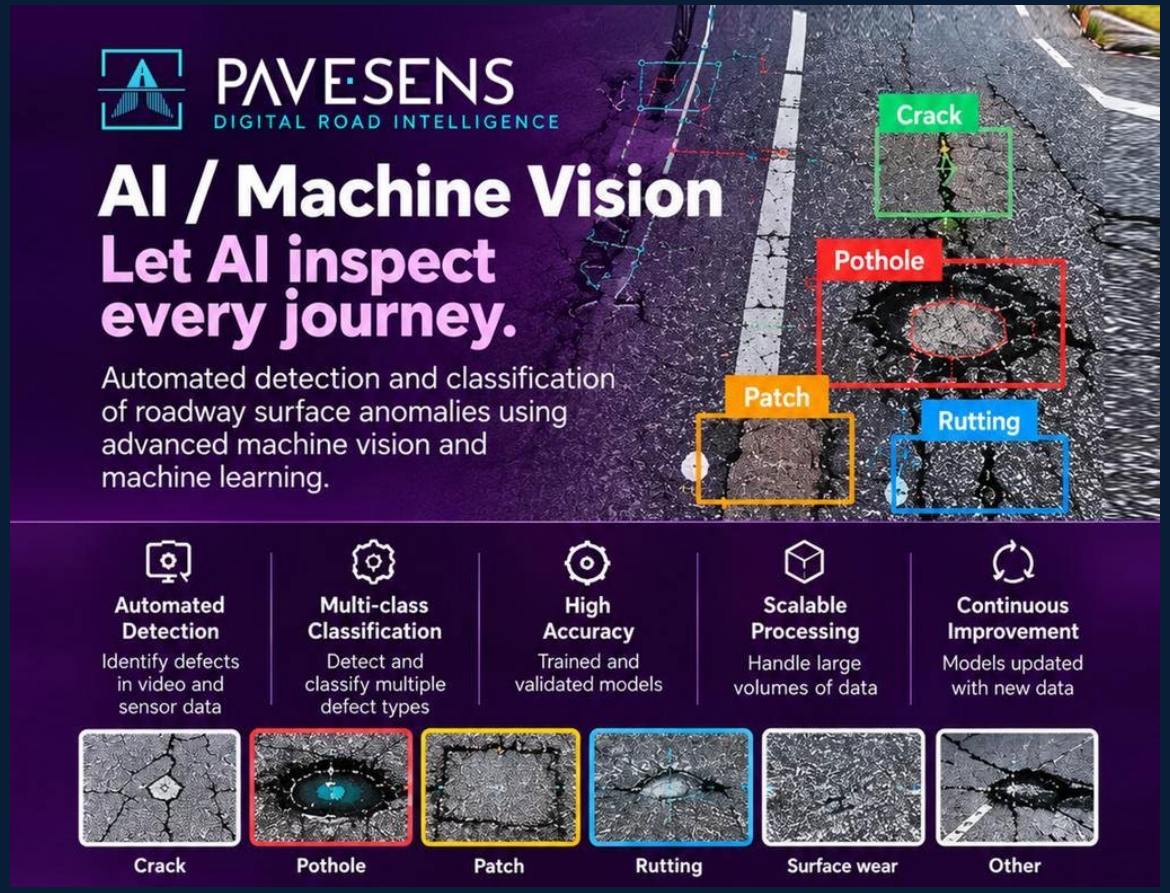
synchronized vibration observations

70,000+

georeferenced roadway videos

Nicosia, January–June 2026. Passenger vehicles and public transport buses

AI and vision support defect verification



Detection

Locate a candidate feature

Classification

Infer a defect category

Verification

Check imagery and field evidence

Product illustration. Performance requires independent field validation

DSS: inspect the underlying observation



Detail of an operational screenshot. Labels and confidence support engineering review

Inspect

Class and anomaly label

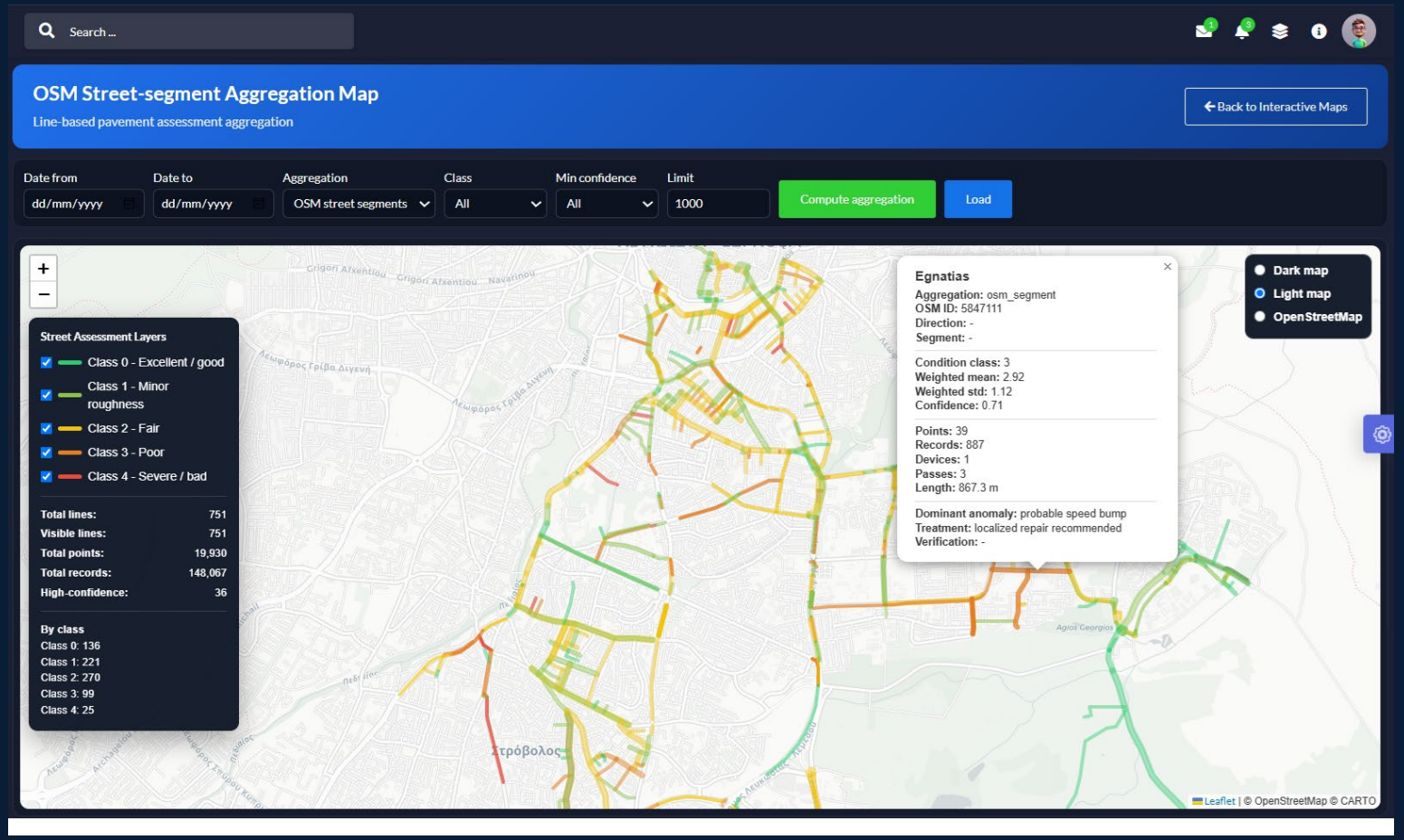
Check

Context and confidence

Verify

Supporting imagery

DSS: aggregate onto road segments



Operational screenshot. Condition estimates remain linked to their evidence

Locate

Persistent spatial patterns

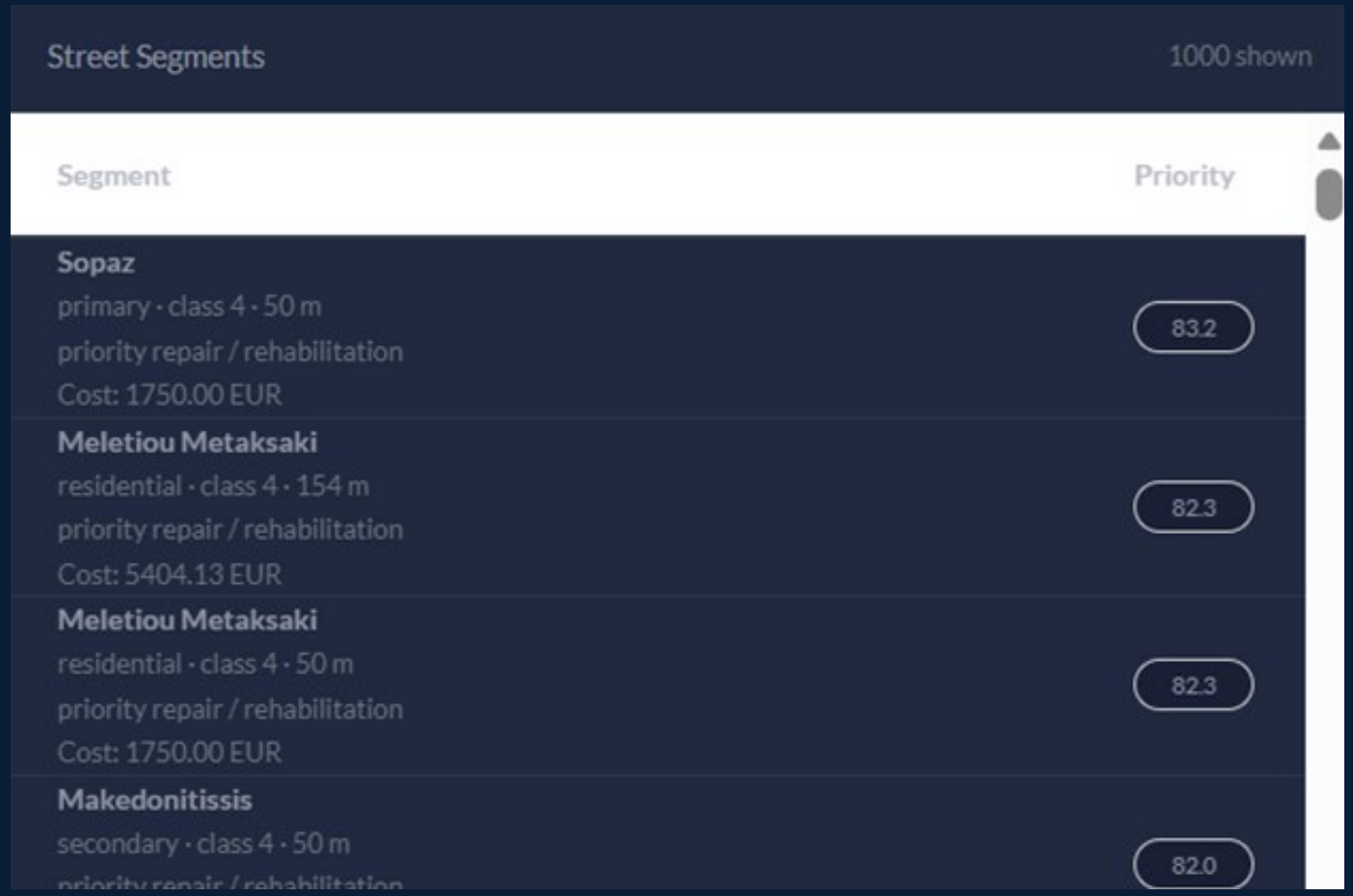
Review

Passes and support

Prioritise

Candidate sections

PMS: priorities and recommended actions



Detail of the priority list. Estimated costs and treatment rules need local verification

Rank

Needs and road context

Recommend

Action and verification

Approve

Engineering responsibility

The connection to agency works management

PAVE-SENS evidence and support

Georeferenced observations
DSS condition and confidence
PMS priorities and recommended actions

Agency integration to define

Approved work orders and ownership
Delivery status and actual costs
Completion evidence and asset updates

Proposed integration workflow. Implementation depends on the agency systems

Bus routes add operational context

Route exposure

Where does the service encounter poor condition?

Intervention timing

How could works affect operations?

Shared urban context

Traffic and environmental indicators



Bus Operations concept artwork. Operational benefits require evaluation

PAVE-Watch adds participatory evidence

Report

Location, description and supporting media

Review

Check duplicates and corroborating evidence

Respond

Assign ownership and communicate status



PAVE-Watch concept artwork. Contributions need review and privacy arrangements

A pilot should test the agency decision

Pilot question	Measure to agree
Is the evidence usable?	Coverage, recency and repeatability
Are detections reliable?	Independent labels, misses and false detections
Does the workflow help?	Verification effort and time to an approved action
Does it improve delivery?	Cost per accepted road-km and treatment outcomes

Proposed evaluation plan. Acceptance criteria should precede collection

Monitoring becomes valuable when someone acts

A clear condition record

Useful evidence starts with type, severity, extent and context

A justified intervention

Urgency, suitability and benefit shape the programme

An accountable feedback loop

Completed works update evidence for the next decision

Discussion and next steps

Which decision would better pavement evidence change?

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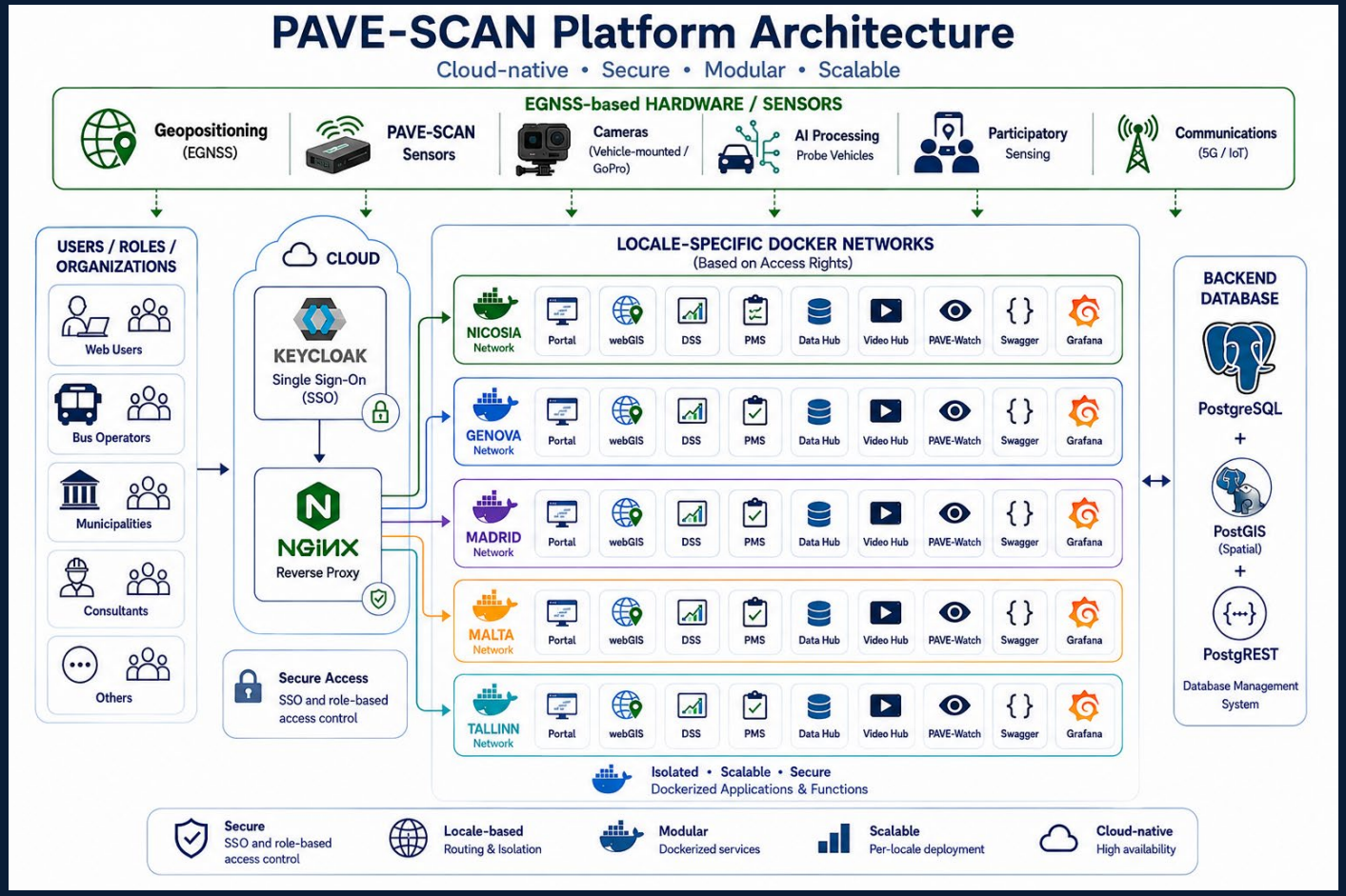
PAVE-SCAN consortium
European Union / EUSPA, Horizon Europe
Grant Agreement 101131910

Platform architecture



Detailed architecture reference. Configuration and deployment status are separate

A common method across deployment locations

NICOSIA

Cyprus

TALLINN

Estonia

MALTA

Malta

MADRID

Spain

GENOVA

Italy

Locations as listed in the finalized talk. Nicosia supplies the reported acquisition dataset

Worked example of an index calculation

RQI = 3.2 **SR = 3.5**

$$PQI = \sqrt{(3.2 \times 3.5)} = \sqrt{11.2} \approx 3.3$$

The components still matter when selecting an intervention

Invented inputs for arithmetic demonstration. MnDOT 2011 definitions

Minnesota DOT reference guidance

Distress and inspection

Pavement Distress Identification Manual, July 2011

Treatment and operations

Pavement Preservation Manual, revision 25 February 2020
Maintenance Manual, Chapter 3, 29 November 2018

Investigation and data quality

Pavement Design Manual, Chapters 2 and 9
Pavement Data Quality Management Plan, 10 May 2018

Full source URLs and edition notes appear in speaker notes

Digital pavement intelligence references

Primary framework and operational evidence

Christodoulou (2026). An Integrated Hardware–Software Platform for EGNSS-Enabled Digital Pavement Intelligence and Low-Cost Continuous Roadway Monitoring. Manuscript submitted 21 July 2026.

Related research

Kyriakou et al. (2021). Spatial Roadway Condition-Assessment Mapping Utilizing Smartphones and Machine Learning Algorithms. Transportation Research Record, 2675(9), 1118–1126.

Product information: PAVE-SENS digital road intelligence

Operational results, illustrations and proposed workflows have distinct evidence status