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# Roadway Pavement Assessment Using Low-Cost EGNSS-based Vibration Sensors, Video Streams and AI

## The PAVE-SCAN Project

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EUSPA
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# Project Overview and Key Objectives

## PAVE-SCAN

- ✓ aims at the development of an EGNSS-based hardware/software solution for the **low-cost automated assessment** of roadway transport networks using **low-cost sensors** (vibration, gyroscope, OBD, lidar), participatory sensing, **machine vision**, and **machine learning**;
- ✓ aligned with the **"European Transport R&I Policy"** and with most EU-member national "Smart Specialization Strategy" objectives;
- ✓ is in response to, and in alignment with, the Horizon Europe Call for the development and implementation of "EGNSS-based technologies in long lead time market segments such as road transportation… in response to the increasing mobility demands and emerging transport solutions", and with proposed activities expected to achieve **TRL 7-9** by the end of the project;

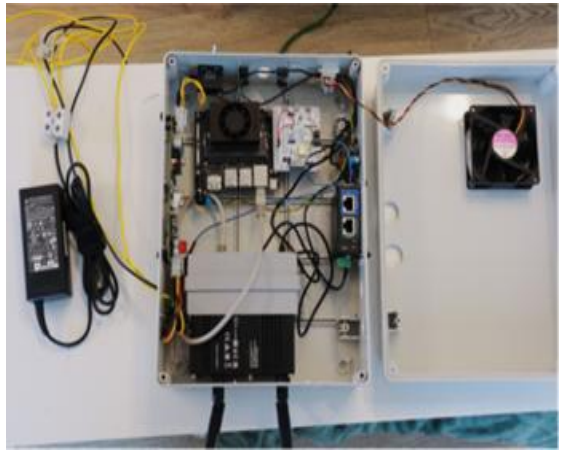
## The Project At A Glance:

- ✓ 13 beneficiaries (in 7 EU countries)
- ✓ 3-year duration (2023-2026)
- ✓ ~€3.0 million budget
- ✓ TRL 7-9
- ✓ 5 pilot sites
- ✓ ~35 devices to be deployed

# Key PAVE-SCAN technologies & outputs

- ✓ Cameras for pavement scanning, and

  3D cameras For depth estimation



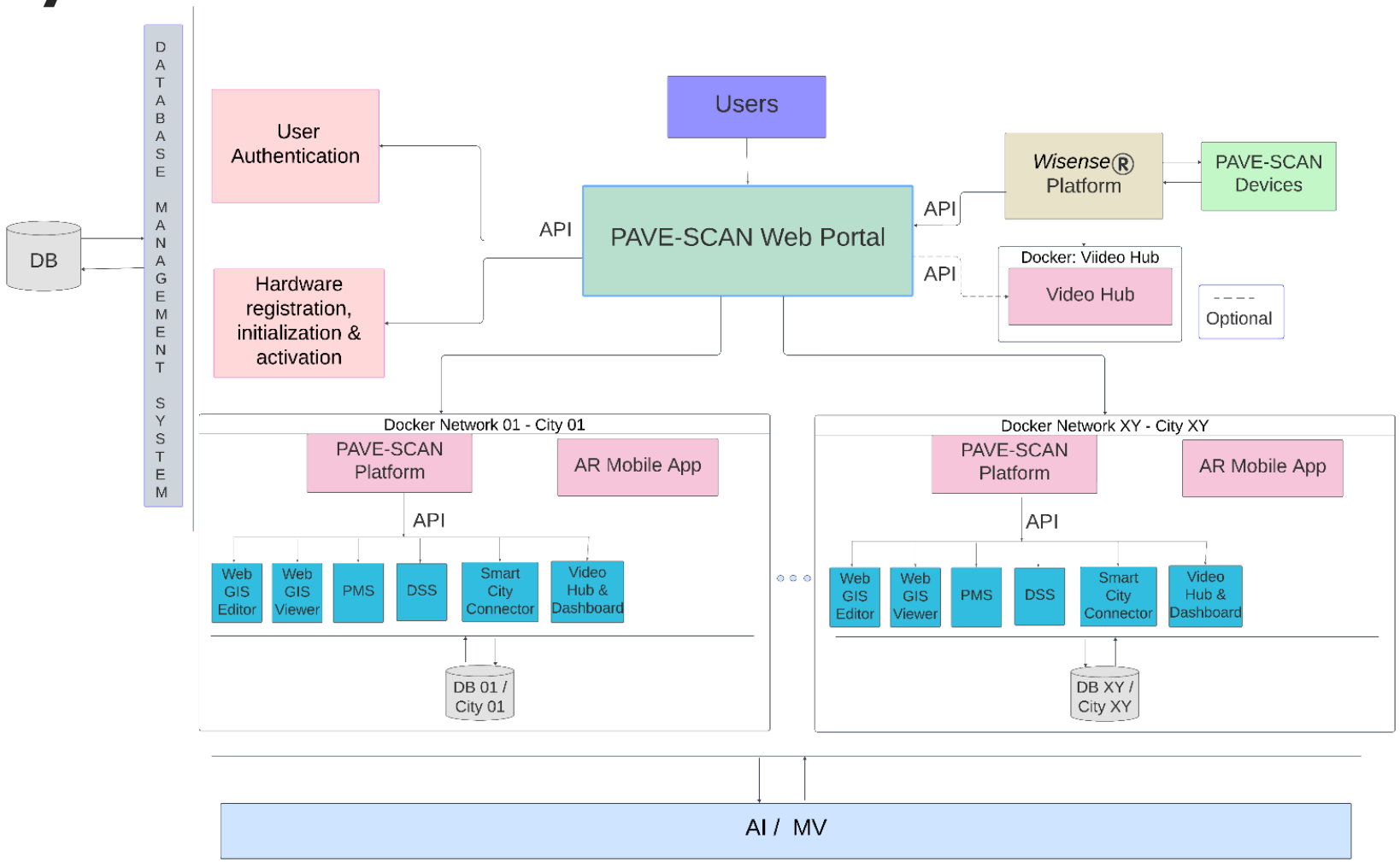
- ✓ Custom hardware: EGNSS sensor devices
- ✓ EGNSS sensor devices (3 different types: for Bus Operators, Municipalities and Advanced Users)


- ✓ Participatory sensing using probe vehicles and AR mobile application

# PAVE-SENS System Architecture

The architecture features :

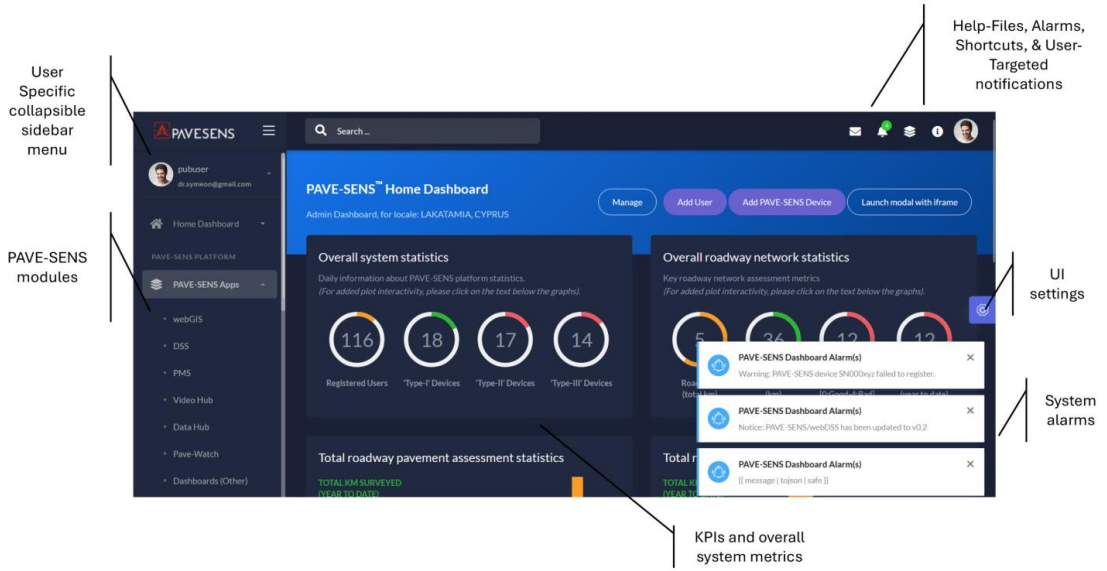
1. **Single-Sign-on** (SSO) / RBAC using Keycloak
2. **Dockerized services** to scale to multiple locales
3. A **Video Hub** to store the videos captured by the cameras
4. A **Data Hub, APIs and Dashboards**: online data browser for the PAVE-SCAN RDBMS
5. **DSS/PMS/GIS** applications
6. **AI** modules



# PAVE-SENS Software

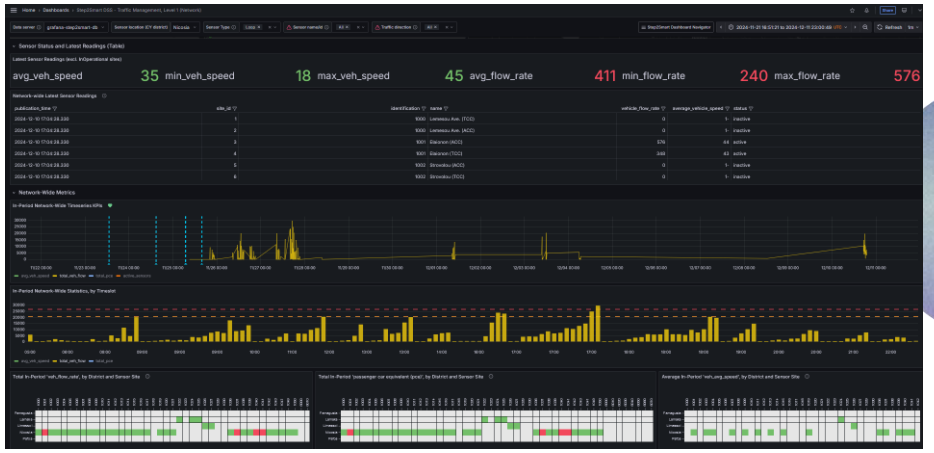
## Python-Driven Software Modules

- ✓ **AI-driven Decision Support System (DSS)**
- ✓ Pavement Management System (PMS)
- ✓ WebGIS
- ✓ WebPortal
- ✓ Augmented-Reality (AR) mobile app
- ✓ **AI/MV module (for the detection and classification of roadway anomalies)**
- ✓ Video Server
- ✓ RDBMS (PostgreSQL)
- ✓ APIs
- ✓ Visualizations




✓ PAVE-SENS Home Dashboard

✓ WebGIS




✓ Grafana Visualizations

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# The Challenge

## Traditional Methods

Manual road inspection is labor-intensive, subjective, and inconsistent.

Detecting and classifying pavement defects requires expert knowledge and is prone to human error.

## PAVE-SENS

Automate pavement anomaly detection using AI-powered computer vision, enabling rapid, accurate, and consistent assessment of road infrastructure across Europe.

**7**
Types of Pavement Anomalies Detected

**100K+**
Training Images

**Real-Time**
Detection Speed

# AI Module Objectives & Challenges

## Primary Objectives

- ✓ Develop an end-to-end AI module for pavement assessment
- ✓ Leverage state-of-the-art deep learning architectures
- ✓ Ensure privacy (GDPR compliance) through automated face and license plate blurring
- ✓ Integrate with PAVE-SENS digital platform
- ✓ Enable continuous model improvement through validation

## Key Challenges Addressed

- ✓ Dataset harmonization from multiple heterogeneous sources
- ✓ Class imbalance across different defect types
- ✓ Real-world variability in lighting and camera perspectives
- ✓ Computational efficiency / Scalability as more locales are added

# Two-Phase Approach

## Model Training

**Where:** Offline, on powerful GPU infrastructure

**What:** Learning patterns from labeled datasets

**Goal:** Create a model that understands what pavement defects look like

**Duration:** Days of intensive computation

## Inference Mode

**Where:** Deployed in production, on PAVE-SENS platform

**What:** Applying learned knowledge to new images

**Goal:** Detection on roads being surveyed

**Duration:** Milliseconds per image

# Dataset Preparation

## Multi-Source Dataset Strategy

Several existing road damage datasets have been used for training.

- ✓ Datasets Characteristics:
  - ✓ Comprise **100K+ images**
  - ✓ Cover **7 countries** across **3 continents**
  - ✓ Account for **varied road** and **weather** conditions
  - ✓ Ensure all **example types** PAVE-SENS will encounter
  - ✓ Focus on **bituminous** pavement distresses

COMING SOON

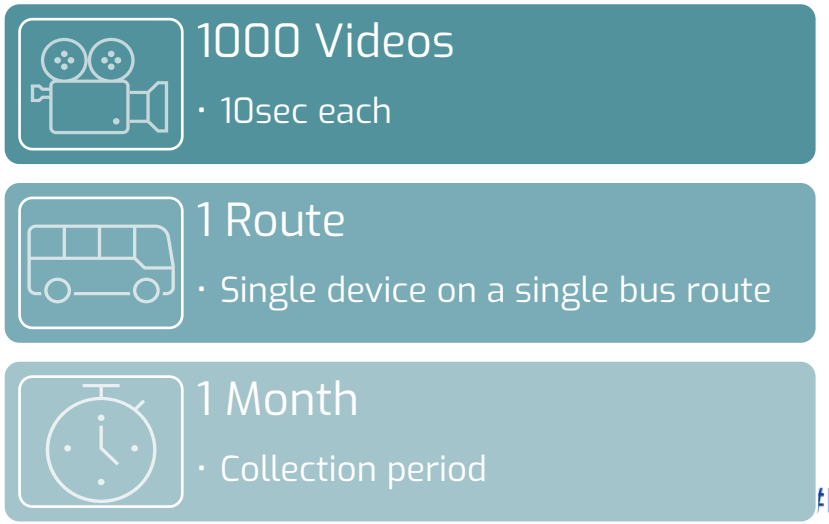
### PAVE-SCAN Field Data Integration

Real-world data collection from operational deployment will be integrated to further enhance model accuracy and adaptability.

## Data Processing Pipeline

- ✓ Unified class mapping across heterogeneous datasets
- ✓ Format conversion (Pascal VOC → YOLO)
- ✓ Stratified split: 80% train, 10% validation, 10% test
- ✓ Photometric and geometric augmentation
- ✓ Perspective normalization and quality validation

## Current PAVE-SCAN Field Dataset Size



# Neural Network Architecture

## YOLO11+ Architecture

**Why YOLO11?** State-of-the-art object detection combining speed and accuracy. Optimized for real-time inference across GPU, CPU, and edge devices.

**Dual-Task Learning:** Simultaneously detects anomalies (where) and classifies them (what type).

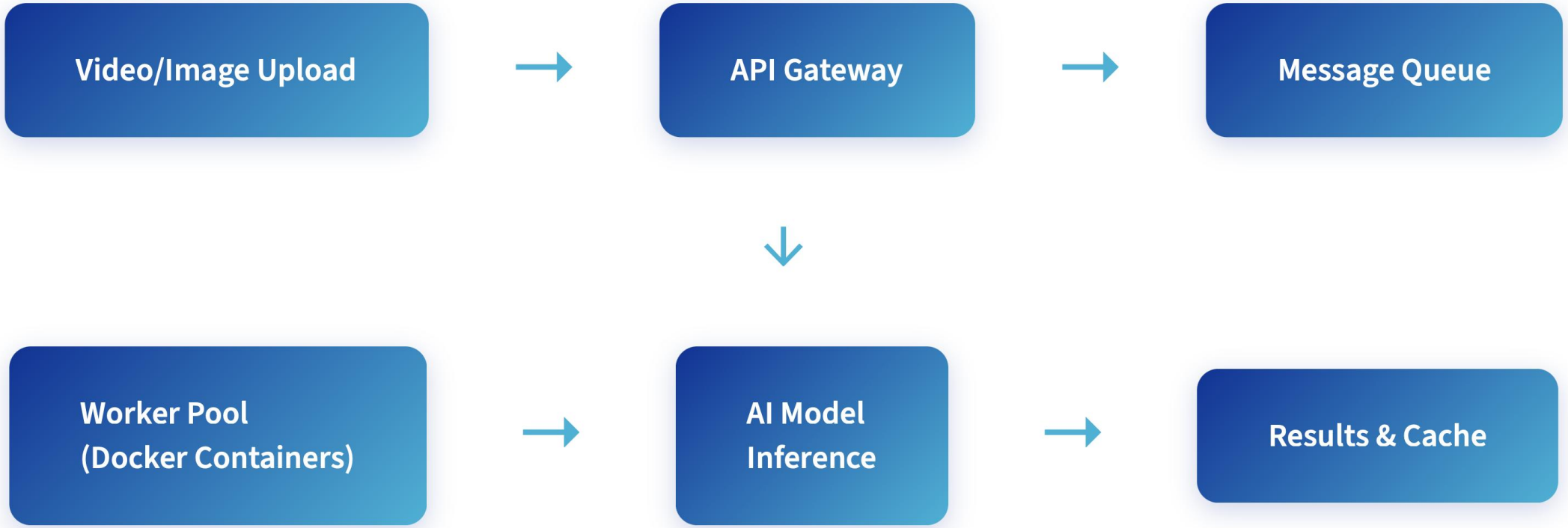
### Training Innovations

- ✓ Transfer learning from COCO dataset
- ✓ CIoU loss for precise localization
- ✓ Adaptive learning rate scheduling
- ✓ Early stopping based on validation performance

**Evaluation Metrics:** mAP@0.5 (primary), Precision, Recall, Per-class performance

**Model Export:** ONNX format for optimized production inference

# From Training to Deployment




### Scalable Architecture

**Microservices** design with load balancing and horizontal scaling for handling variable workloads

### Efficient Processing

**Redis** caching and asynchronous processing via **RabbitMQ** for optimal throughput

# AI Detection in Action


**Performance:** Detects and classifies multiple defects per frame

**Visual Output:** Bounding boxes with confidence scores and defect type labels

# Detection Capabilities

1. Longitudinal Crack
2. Transverse Crack
3. Alligator Crack
4. Pothole
5. Block crack
6. Repair
7. Manhole

**Continuous Improvement**

The model supports periodic retraining with new PAVE-SCAN field data, human validation feedback, and adversarial training to maintain and enhance detection accuracy over time.

# Impact & Future Outlook

## Achievements

- ✓ Production-ready AI module to be integrated on PAVE-SENS platform
- ✓ Harmonized multi-source datasets spanning 7 countries
- ✓ Fast inference capability with optimized ONNX export
- ✓ Scalable microservices architecture with containerization

## Next Steps

- ✓ Integration of PAVE-SCAN field-collected data allows...
- ✓ Dual Input Support: RGB images or RGB + depth maps for enhanced 3D defect detection
- ✓ Integration with AR module
- ✓ Continuous model retraining and validation
- ✓ Extended defect classification with severity levels
- ✓ Privacy-preserving automated blurring integration

**Transforming European Road Infrastructure Assessment**

The PAVE-SCAN AI module represents a significant advancement in automated pavement monitoring, combining cutting-edge deep learning with practical deployment considerations to deliver accurate, scalable, and privacy-conscious road assessment across Europe.

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