SENSUS

Artificial empathy for autonomous driving

Students
Daniel Pipitone
Leonardo Cecchini

Market Opportunity

Projected to reach $4.4 Trillion by 2034

$273B

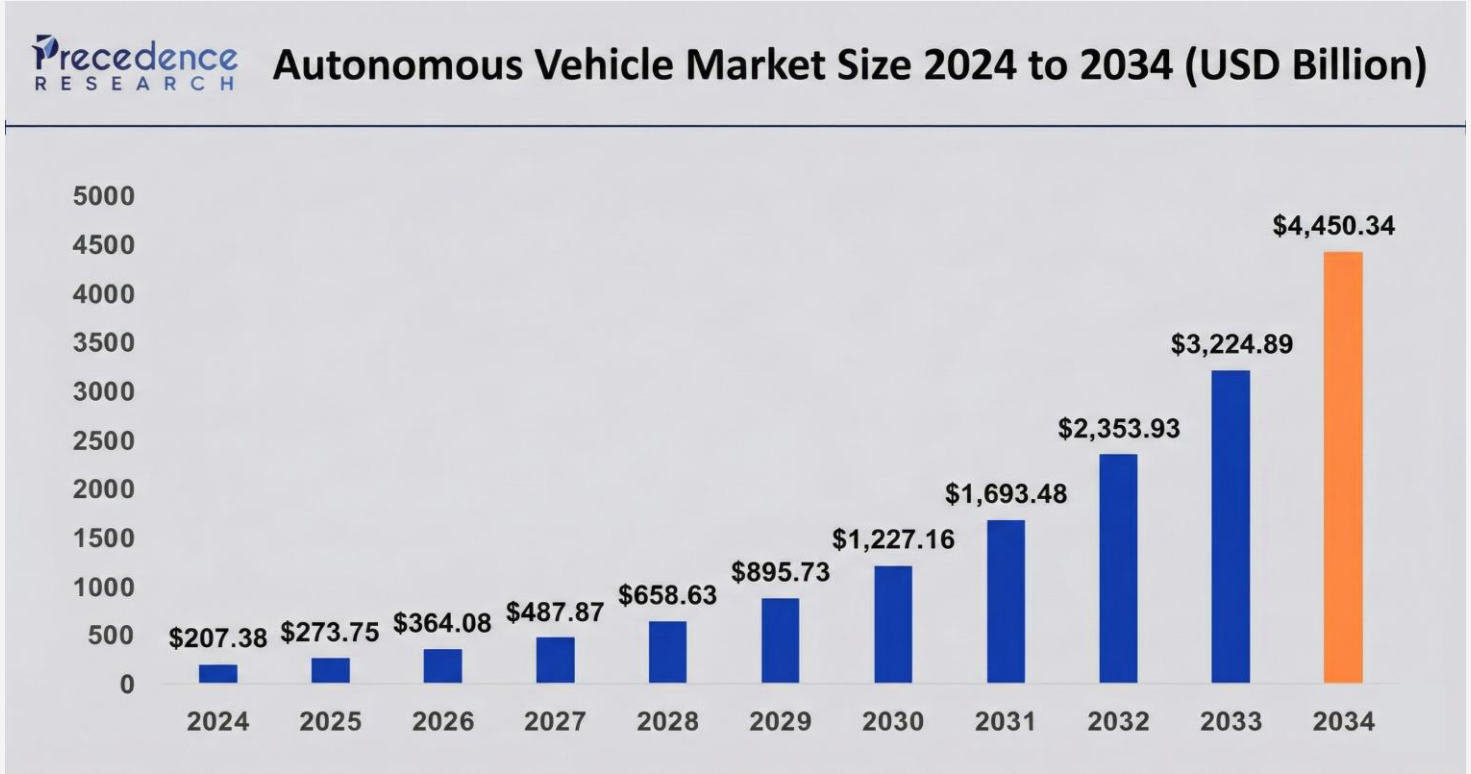
Market Value 2025

$4.450B

Projection 2034

36,3%

CAGR (Annual Growth)



BUT…**passenger trust** and **comfort** are key elements for acceptance

Source: https://www.precedenceresearch.com/autonomous-vehicle-market

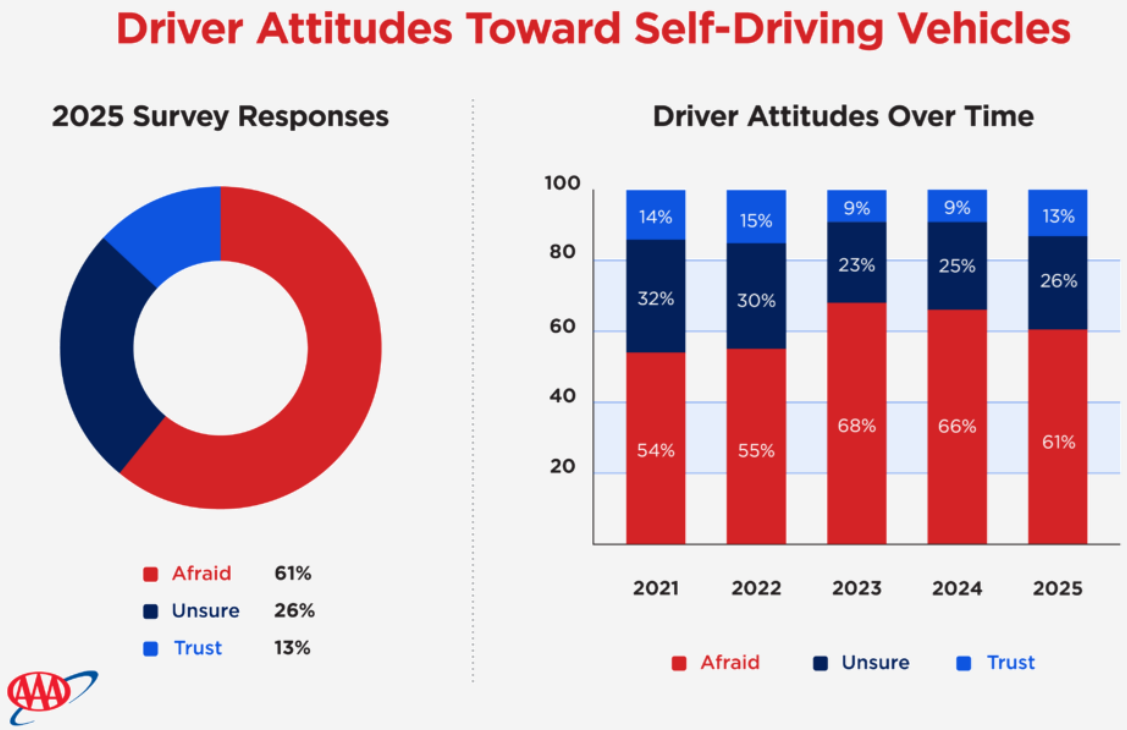
The Problem

Anxiety: The Main Barrier to Adoption

61% People are **afraid** of autonomous vehicles

74% Specific fear of **robotaxi**

53% **Would not choose** to use them



Source: https://newsroom.aaa.com/2025/02/aaa-fear-in-self-driving-vehicles-persists/

Identified Anxiety Factors

External Factors

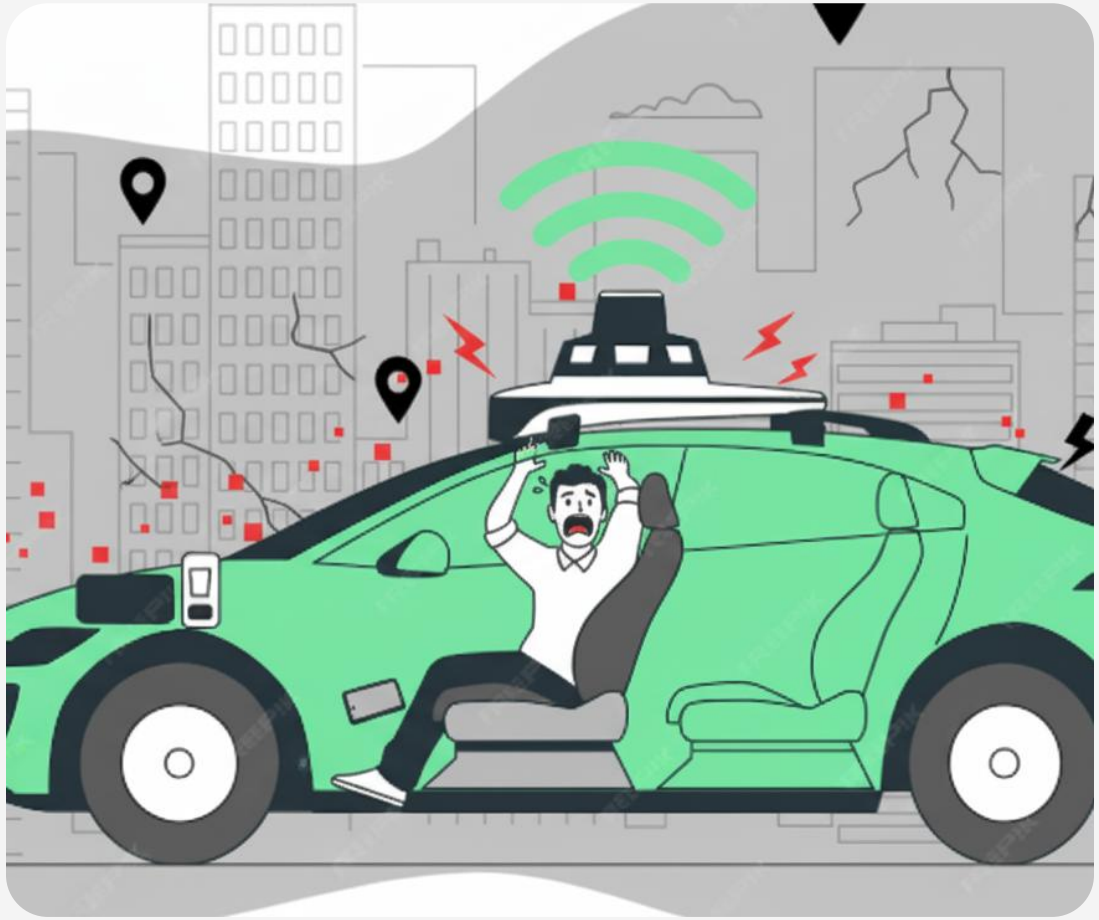
- Cutting the road from other vehicles
- Tight turns and complex maneuvers
- Pedestrians crossing suddenly

System Factors

- GPS and navigation errors
- Lack of real-time information
- Unexpected speed changes

Psychological factors

- Loss of control
- Lack of perceived reliability
- Uncertainty about system decisions



Source: https://aodr.org/xml/41432/41432.pdf

State of art - Papers

Scientific basis of the solution

Biometric Monitoring

GSR, HR, and HRV as reliable markers of **emotional state**.

Source: ACM Conference on Human Factors, 2020

Eye tracking and anxiety

Increased visual exploration predicts anxiety. Eye patterns serve as an early indicator of **emotional distress**.

Source: SCITEPRESS Science & Technology Publications, 2023

Ambient illumination

LED colors can produce a significant **calming effect**

Source: KTH Royal Institue of technology, 2024

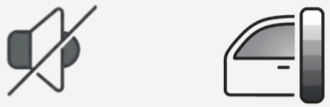
Multi-Sensory Approach

Personalized music + Aromatherapy lead to significant **stress reduction** and improved perceived comfort.

Source: Frontiers in Psychology, 2021; NIH, 2024

Competitor Analysis

Competitive landscape and existing solutions

Company	Solution	Approach	Limitation
Mercedes-Benz	ENERGIZING Comfort		**No Bio-Feedback** System cannot verify or adapt to passenger reaction
VOLVO	Cabin Cocoon (360c)		**Passive Isolation** No active emotion regulation.

GAP: Lack of **Real-Time Feedback, AI-Driven** Emotional Regulation.

Patents

US10981563B2

Lighting & Sound Control

Mood control system based on lighting and sound

2021

US20210155263A1

Passenger Stress Detection

Environment adaptation based on passenger stress detection

2021

US20210245657A1

Adaptive Lighting System

improve comfort by adapting lighting based on the emotional state of the occupants

2023

US20220169284A1

Biometric Eye-Tracking

Stress detection through eye movement analysis

2024

US20250239165A1

Stress Mitigation Techniques

Multiple stress mitigation techniques for autonomous vehicles

2025

US20220169284A1

Environment Adjustment

Monitor the status of the passenger and adjust the environment accordingly

2025

GAP: Major players are filing patents on **single components** (Sensors or Lights)

The SENSUS Logic Loop

Continuous Monitoring

Real-time acquisition of biometric data

AI Anxiety Processing

Computes anxiety score

Dynamic Adaptation

Modulates environment to restore calm

System Architecture

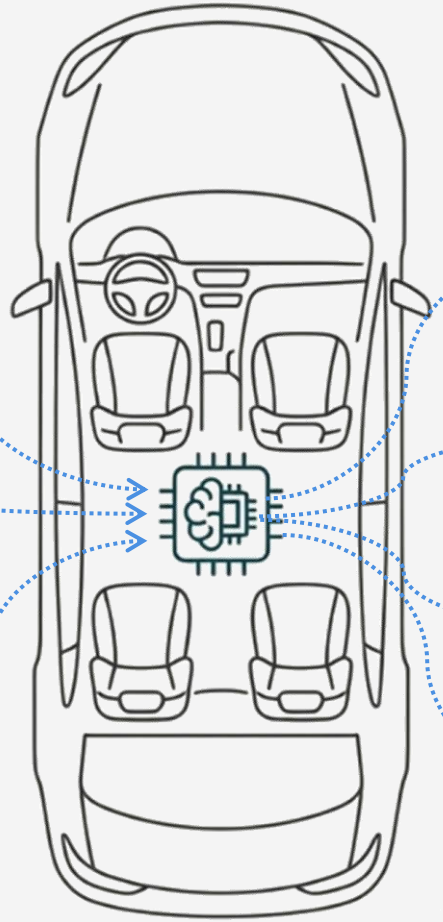
An adaptive ecosystem for well-being

Input: Continuous Biometric Monitoring

Face Camera
Eye tracking

PPG in seat/belt
Heart rate

GSR on armrest
Galvanic skin response



Output: Real-Time Adaptive Environment

Adaptive lighting
Tonality and intensity modulation

Soundscapes
Custom music and noise cancellation

Aromatherapy
Diffusion of calming fragrances

Dynamic windows
Gradual opaque

Comparison table

Competitive Advantage: Feature-by-feature analysis

Feature	SENSUS	Mercedes	Volvo	Denso (*)	Textron (*)
Anxiety detection	✓	-	-	✓	✓
Eye tracking	✓	-	-	✓	-
Adaptive lighting	✓	✓	-	-	✓
Aromatherapy	✓	✓	-	-	-
Adaptive music	✓	✓	-	-	✓
Dynamic windows	✓	-	✓	-	-
Continuous Feedback	✓	-	-	✓	✓

SYSTEM SPECIFICATION

Functional Requirements, Architecture & Tech Stack

Functional Requirements

System features enabled by SENSUS Core technology

PASSENGER

Experience & Control

FR_P_01	The system visualizes anxiety levels in real time based on sensor data
FR_P_02	The system sends a visual notification when environmental changes are triggered.
FR_P_03	The system disables specific actuators on command of the HMI interface.

FLEET MANAGER

Data & Optimization

FR_M_01	The system aggregates anxiety data and displays it on a geographical map
FR_M_02	The system calculates and reports the percentage of successfully completed interventions.
FR_M_03	The system generates an alert when the consumable level drops below the preset threshold.

TECHNICIAN

Maintenance & Calibration

FR_T_01	The system performs the calibration procedure for the Eye-Tracking sensor.
FR_T_02	The system performs diagnostic tests on the actuators and returns the operational status
FR_T_03	The system installs firmware updates for the Emotion Engine.

Non-Functional Requirements

Constraints for Performance, Privacy, Safety & Usability

Performance & Consumption

NFR_P_01 System latency between sensor detection and actuator triggering **< 200ms**

NFR_P_02 Complete system boot time **< 3 seconds** from vehicle ignition.

NFR_C_01 Peak power consumption **< 50W** during maximum intervention .

NFR_C_01 Standby consumption < 2W after 30s of passenger absence .

Reliability & Maintenance

NFR_R_01 **Fail-Safe Mechanism**: System shuts down immediately without interfering with driving in case of crash.

NFR_R_02 **Graceful Degradation**: System maintains partial functionality if a single sensor fails.

NFR_M_01 **Calibration Stability**: Sensors require no manual recalibration for > 3 years or 100,000 km

Usability

NFR_U_01 Environmental interventions fade-in duration **> 2** seconds to minimize cognitive load .

NFR_U_02 UI comprehension time **< 1** second (intuitive icons, minimal text) .

Constraints

Technical and regulatory constraints for a safe integration

REGULATORY & PRIVACY

`CNS_L_01` **GDPR & AI Act Compliance**: Biometric data must be processed entirely locally (Edge) with no raw data export .

ENVIRONMENTAL & HARDWARE

`CNS_E_01` **Operating Range**: Hardware must withstand temperatures from -20°C to +85°C and automotive-grade vibrations

PHYSICAL INTEGRATION

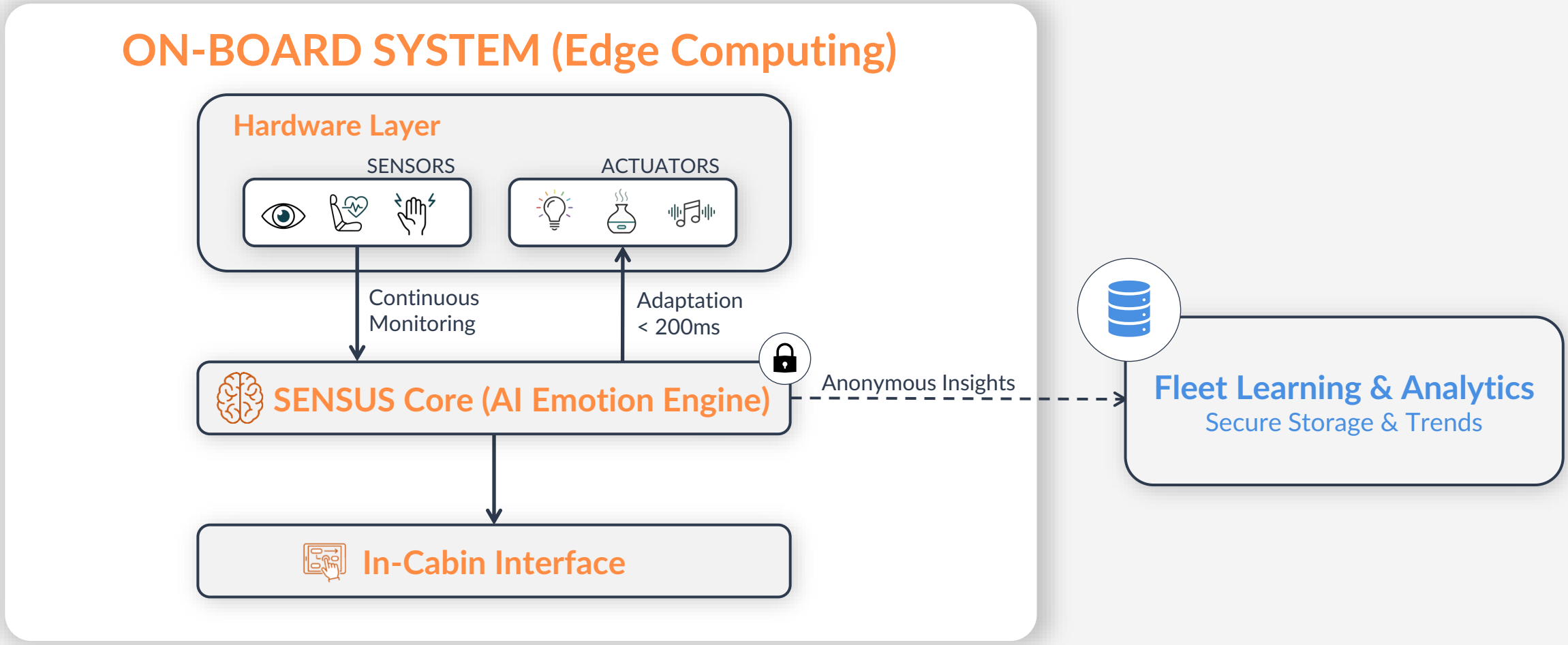
`CNS_S_01` **Decoupling**: Physical isolation from braking/steering systems

`CNS_S_02` **Passive Safety**: Sensors must not obstruct airbag deployment areas

DEVELOPMENT & SOURCING

`CNS_D_01` **COTS Mandate**: > 80% of hardware must be Commercial Off-The-Shelf components to ensure procurement speed .

System Architecture



Biometric Sensing Layer

Smart NIR Vision

Night Vision & Eye Tracking

Resolution: 720p

Speed: 30fps

Tech: IR-Sensitive

Source: InvisibleEye, 2017

Source: CMP FEL CVUT, 2016

Seamless PPG

Heart Rate & HRV Analysis

Signal: Green + IR Spectrum

Precision: 50Hz Sampling

Source:*TI Technical Article SSZT538, 2023*

Source: *Nature Sci Rep 5:10494, 2015*

Precision GSR

Skin Conductance Analysis

Range: 10kΩ-10MΩ

Output: 0-3.3V

Source:*PMCID: PMC3386730, 2012*

Immersive Actuation Layer

Adaptive Lights

Single pixel control

Digital RGB

Single Pixel Control

30 LED/m

Invisible Sound

Invisible & Vibration

5W RMS Exciters

Contact Vibration

No Visible Grills

Smart Scent

Fast & No heat

Ultrasonic (113kHz)

Instant On/Off

No Heat

Privacy Glass

Easy to install

PDLC Film

Adhesive

Voltage Controlled

Source: NCBI PMC5224704


PPG Sensor & Audio
in Headrest
Dynamic Window
Integrated Eye
Tracking Module
GSR Conductive Fabric
Aromatherapy
Diffuser
Adaptive
Ambient Lights

WORK PACKAGES

The fundamental units of work of the project

Work Breakdown Structure

Parallel & modular development for fast validation

WP 1

Project Management & Architecture

RI (Industrial Research)

WP 2

Hardware Setup & Sensor Integration

RI (Industrial Research)

WP 3

AI Core & Emotion Engine

RI (Industrial Research)

WP 4

HMI & Environmental Actuation

SS (Software Development)

WP 5

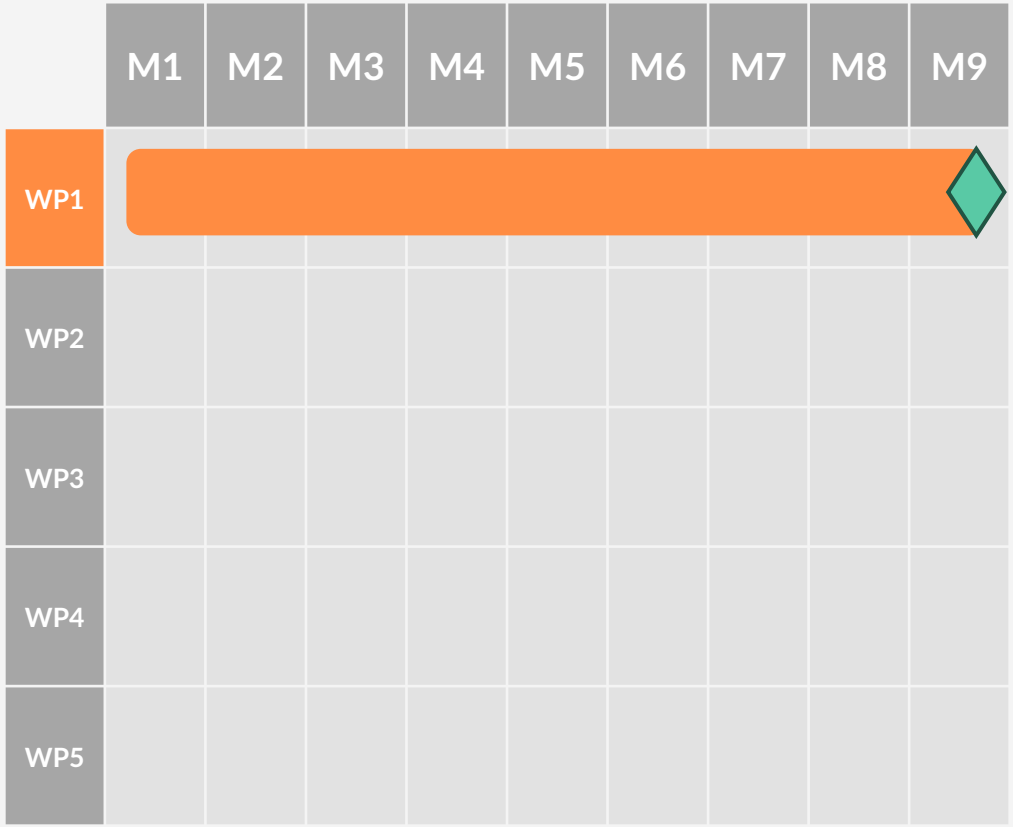
Integration & Validation

SS (Software Development)

WP1 — Project Management & Compliance

Foundation of system architecture, privacy and safety

RI (Industrial Research)



MOTIVATION

Ensure project coordination, legal compliance (GDPR/AI Act), and define a safe system architecture decoupled from vehicle driving systems.

GOALS

1. **Define** Functional & Non-Functional Requirements.
2. **Validate** Privacy & Safety protocols.
3. **Coordinate** procurement and budget.

WP1 — Project Management & Compliance

Foundation of system architecture, privacy and safety

RI (Industrial Research)

TASKS

T1.1: Requirements Drafting: Definition of system specifications and "Privacy by Design" architecture.

T1.2: Compliance Analysis: Risk assessment for GDPR (Data Minimization) and Safety (interference check).

T1.3: Procurement: Selection and purchase of COTS hardware components.

TEAM & COST

Project Manager: € 3k/month
Legal Consultant: € 3k/month
Total WP Budget: € 54,000

DELIVERABLES

D1.1 System Architecture Doc
D1.2 GDPR Compliance Report

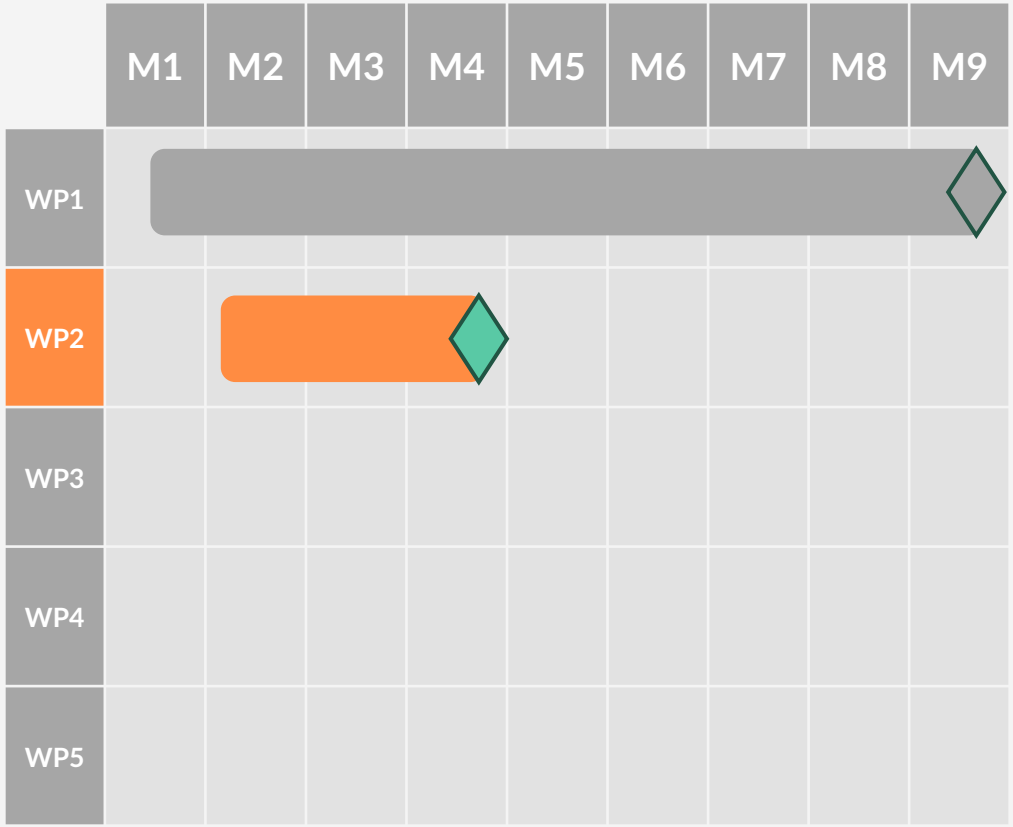
MILESTONES

M1.1 Project Closure & Final Report

WP2 - Hardware Setup & Sensor Integration

Building the Edge Hardware for Real-Time Biometric Monitoring

RI (Industrial Research)



MOTIVATION

Build the physical "Edge" infrastructure to host the AI, ensuring non-invasive sensor integration

GOALS

1. **Setup** local processing unit (Edge Computing).
2. **Integrate** sensors into the seat/cockpit.
3. **Develop** low-level drivers for raw data acquisition.

WP2 - Hardware Setup & Sensor Integration

Building the Edge Hardware for Real-Time Biometric Monitoring

RI (Industrial Research)

TASKS

T2.1: Sensor Selection: Comparative analysis of automotive-grade sensors.

T2.2: Hardware Prototyping: Design of 3D-printed housing and cabling.

T2.3: Driver Development: Implementation of interfaces to read sensor data streams.

TEAM & COST

Embedded Eng: € 2.5k/month
Hardware Components: € 10k
Total WP Budget: € 17,500

DELIVERABLES

D2.1 Hardware Prototype
D2.2 Sensor Interface Specs

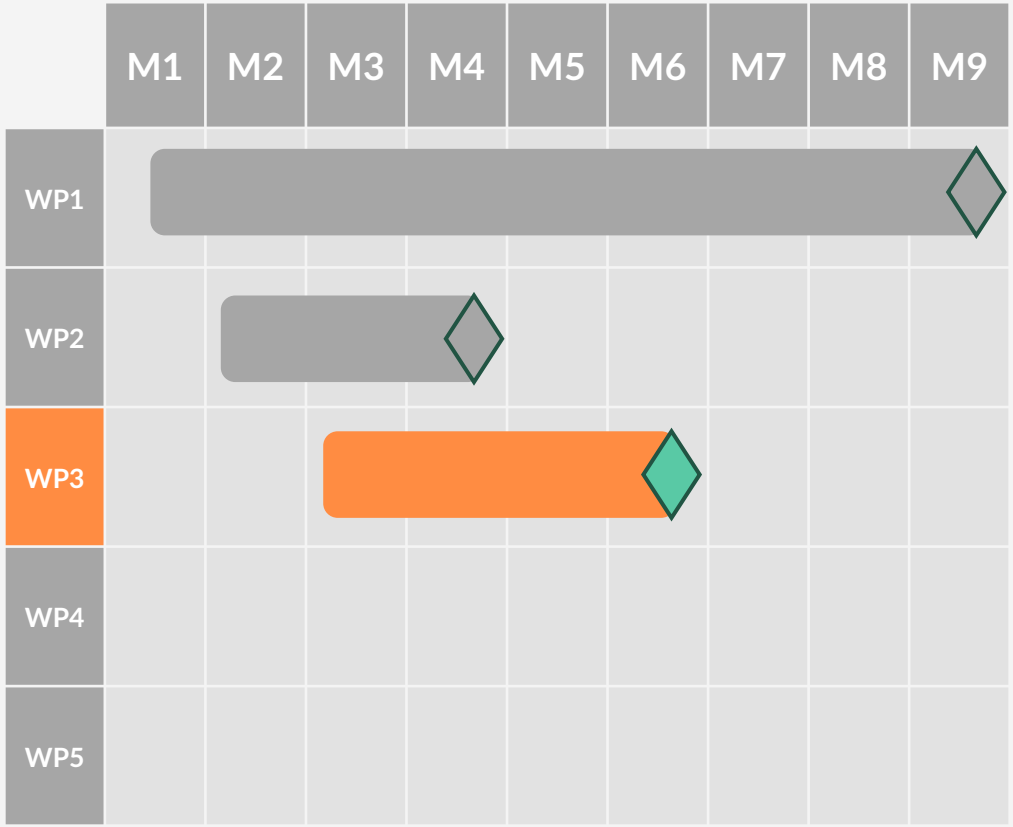
MILESTONES

M2.1 Hardware Assembly Complete

WP3 - AI Core & Emotion Engine

Transforming Biometric Signals into a Real-Time Anxiety Index

RI (Industrial Research)



MOTIVATION

Create the core intelligence capable of translating biometric signals into an anxiety index in real-time.

GOALS

1. **Train** Computer Vision models for facial expression.
2. **Develop** Data Fusion algorithms (Face + Heart Rate).
3. **Optimize** models for low-latency Edge execution.

WP3 - AI Core & Emotion Engine

Transforming Biometric Signals into a Real-Time Anxiety Index

RI (Industrial Research)

TASKS

T3.1: Model Training: Training and fine-tuning on automotive datasets.

T3.2: Fusion Algorithm: Developing logic to merge visual and physiological data.

T3.3: Edge Optimization: Quantization of models to fit embedded constraints.

TEAM & COST

AI Specialist: € 2.8k/month
Cloud/Data: € 5k
Total WP Budget: € 16,200

DELIVERABLES

D3.1 Trained AI Models
D3.2 Anxiety Classification Algorithm

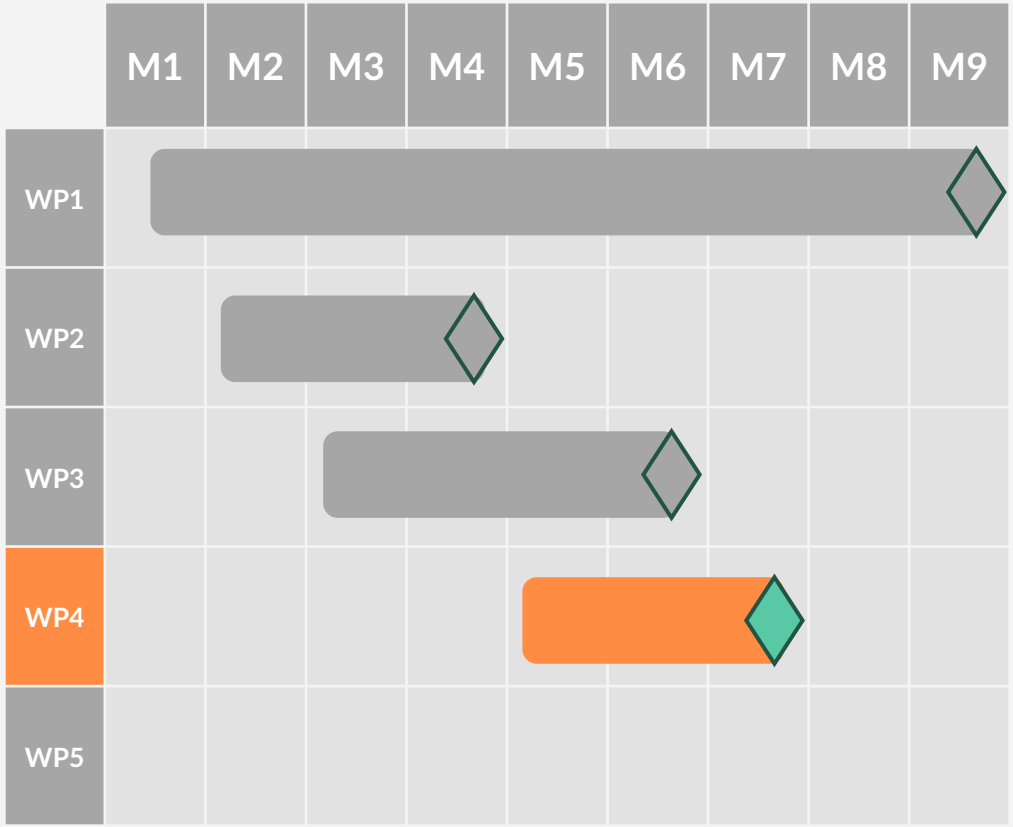
MILESTONES

M3.1 AI Model Beta Release

WP4 - HMI & Environmental Actuation

Human-Machine Interface for Trust and Transparency

SS (Software Development)



MOTIVATION

Create a transparent interface to build user trust and provide granular control over environmental adaptations.

GOALS

1. **Design** a minimal UI for the in-car display.
2. **Implement** the Manual Override logic.
3. **Develop** the notification system for real-time bio-feedback.

WP4 - HMI & Environmental Actuation

Human-Machine Interface for Trust and Transparency

SS (Software Development)

TASKS

T4.1 UI/UX Design: High-fidelity mockups for anxiety visualization and actuator status.

T4.2 Control Logic: Backend development for user-triggered overrides.

T4.3 HMI Integration: Deploying the interface on the vehicle's tablet/display system.

TEAM & COST

IoT/Backend Engineer: € 2.5k/month
Frontend Dev: € 2.5k/month
Total WP Budget: € 15,000

DELIVERABLES

D4.1 HMI Software Module
D4.2 UX Validation Report.

MILESTONES

M4.1 Interface Beta Release

WP5 - Integration & Validation

On-Board Integration & Cloud Fleet Intelligence

SS (Software Development)

MOTIVATION

Finalize the end-to-end data flow, ensuring that local processing meets the <200ms latency requirement.

GOALS

1. **Integrate** On-board AI with Cloud Fleet management
2. **Perform** stress tests on system latency
3. **Validate Privacy-by-Design** protocols

WP5 - Integration & Validation

On-Board Integration & Cloud Fleet Intelligence

SS (Software Development)

TASKS

T5.1 End-to-End Integration: Connecting sensors, AI core, and actuators.

T5.2 Cloud Gateway: Setting up secure, anonymized data transfer for fleet analytics.

T5.3 Performance Testing: Measuring response times and sensor accuracy in moving vehicle simulations..

TEAM & COST

System Integrator: € 2.5k/month
QA Engineer: € 2.5k/month
Total WP Budget: € 15,000

DELIVERABLES

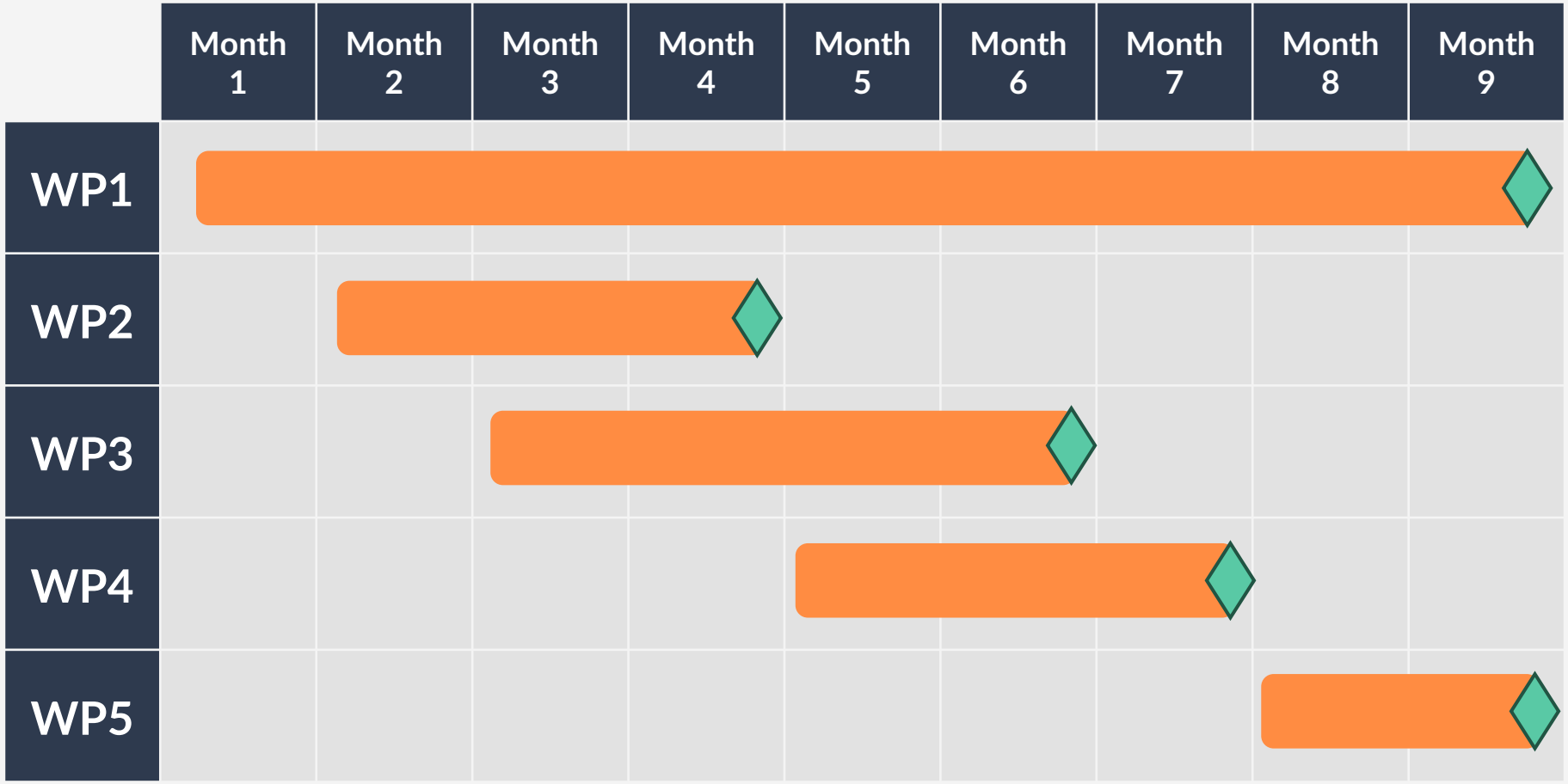
D5.1 Fully Integrated Prototype

D5.2 Security Audit Report.

MILESTONES

M5.1 System Prototype Ready

WP – Summary


Month 1
Month 2
Month 3
Month 4
Month 5
Month 6
Month 7
Month 8
Month 9
WP1
WP2
WP3
WP4
WP5

RISKS

Key Technical Risks and Mitigation Measures

RISKS #1 - AI Performance Risk

RISKS DESCRIPTION

Physiological signals unrelated to anxiety may be **misread** as stress, triggering **unnecessary interventions** and reducing user trust.

STRATEGY

1. Implement a "**Contextual Layer**" that cross-references biometric data with environmental data or inertial data.
2. **Expand** the **training dataset** to include "physical stress" vs. "emotional stress" scenarios.

COSTS **€ 5,000** (Extra Data Scientist hours for dataset refinement and model retraining)

RISKS #2 - Environmental Hardware Risk

RISKS DESCRIPTION

Heavy **reliance** on **COTS hardware** may lead to reliability issues, as consumer components may **not tolerate** the required temperature range (−20 °C to +85 °C) or continuous vehicle vibrations.

STRATEGY

1. Engineering of a **custom ruggedized case** with advanced passive thermal dissipation and anti-vibration mounts

2. Execution of accelerated "Stress Screening" on the initial prototypes to immediately **identify weak points**.

COSTS **€ 7,500 =** **€3,500 for materials** (custom casing, thermal paste, vibration dampeners)
+
€4,000 for Labor (Mechanical & Embedded Engineer).

RISKS #3 - Biometric Data Occlusion & Bias

RISKS DESCRIPTION

Sensors may **fail** in **specific demographics** or **scenarios** e.g.:

- PPG blocked by winter clothing
- NIR eye tracking impaired by polarized sunglasses

STRATEGY

1. Implement a "**Multi-modal Fallback**" logic: if the Camera is blocked, the system relies 100% on the Heart Rate sensor, and vice versa.

2. Organize a User Acceptance Test with a highly diverse volunteer group to **calibrate the sensors**.

COSTS **€ 3,000** (Recruitment of diverse test subjects + extra Field-Testing hours).

RISKS #4 - Chip Unavailability (Shortage)

RISKS DESCRIPTION

Automotive supply chains are prone to **microcontroller** and **AI accelerator shortages.**
If the chosen board becomes unavailable or has long lead times, project timelines can collapse.

STRATEGY

1. **Strategic Stockpiling**: purchasing the critical computing units for all prototypes immediately at Project Start (Day 1).
2. Create a **Hardware Abstraction Layer**, allowing the team to switch to a different computing board if the primary choice is unavailable.

COSTS

€ 4,500 (Inventory carrying costs + Software Architect to write the abstraction layer for portability).

PROFILES

Roles required for the realization of the project

Project Manager | Senior

WP1

Edu: MSc in Management Engineering.

Exp: 5+ Years in R&D Projects.

€ 3,000/mo

Key Responsibilities

- Project coordination
- Stakeholder management.
- Risk analysis monitoring
- Budget control
- Agile Sprint planning.

Technical Toolkit

Hard Skills

- ✓ **Tools:** JIRA • MS Project • Trello
- ✓ **Methodologies:** Agile/Scrum • Waterfall
- ✓ **Standards:** Functional Safety awareness

Soft Skills

- ✓ Leadership
- ✓ Crisis Management
- ✓ Negotiation

Legal Specialist | Senior Consultant

WP1

Edu: Master of Laws (LL.M) in Law & Technology

Exp: **7+ Years** in Tech Law / GDPR.

€ 3,000/mo

Key Responsibilities

- Validation of Data Processing Agreements (GDPR).
- Assessment of AI Act compliance for biometric data.
- Drafting of Liability disclaimers for testing.

Technical Toolkit

Hard Skills

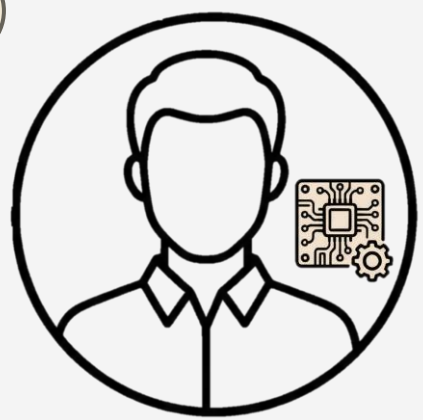
- ✓ **Tools:** OneTrust • LexisNexis.
- ✓ **Knowledge:** GDPR (Art. 9), EU AI Act, Automotive Safety Regulations.

Soft Skills

- ✓ Critical Thinking
- ✓ Attention to Detail
- ✓ Ethics.

Embedded Systems eng. | Mid-Level

WP2



Edu: MSc in Electronic Engineering

Exp: **3 Years** in Firmware/Hardware design.

€ 2,500/mo

Key Responsibilities

- Selection and setup of Edge Hardware
- Design of sensor wiring and isolation circuits.
- Writing low-level drivers for sensor data acquisition.

Technical Toolkit

Hard Skills

- ✓ **Languages**: C, C++, Assembly.
- ✓ **Tools**: Altium Designer , Yocto Project
- ✓ **Hardware:** I2C, SPI, UART protocols.

Soft Skills

- ✓ Precision
- ✓ Hardware Troubleshooting

AI Specialist | Mid-Senior

WP3

Edu: Master in Artificial intelligence

Exp: **3-5 Years** in Machine Learning

€ 2,800/mo

Key Responsibilities

- Training of Facial Expression Recognition (FER) models.
- Development of the Multi-modal Data Fusion Algorithm.
- Optimization of Neural Networks for Edge deployment.

Technical Toolkit

Hard Skills

- ✓ **Languages**: Python, C++.
- ✓ **Frameworks**: PyTorch, TensorFlow, OpenCV
- ✓ **Tools**: Docker, CUDA

Soft Skills

- ✓ Analytical Thinking,
- ✓ Creative Problem Solving.

Frontend Developer | Junior-Mid

WP4

Edu: BSc in Computer Science or Interaction Design.

Exp: 2 Years in Mobile/Web App Dev.

€ 2,500/mo

Key Responsibilities

- Development of the Passenger Dashboard
- Implementation of the "Transparency Layer" UI.
- UX Design integration.

Technical Toolkit

Hard Skills

- ✓ **Frameworks:** React Native, Qt
- ✓ **Tools**: Figma (UI Handoff), Git.
- ✓ **Languages:** JavaScript/TypeScript.

Soft Skills

- ✓ User Empathy
- ✓ Visual Communication.

IoT Software Engineer | Junior-Mid

WP4

Edu: BSc in Computer Science

Exp: **2 Years** in Python scripting & API.

€ 2,500/mo

Key Responsibilities

- Backend logic for Environmental Actuation (Lights/Scent).
- API development for hardware control.
- Implementation of the "Manual Override" safety switch.

Technical Toolkit

Hard Skills

- ✓ **Protocols**: MQTT, REST APIs, Bluetooth Low Energy (BLE).
- ✓ **Languages**: Python, Node.js.Tools: Raspberry Pi OS, Postman (API Testing).

Soft Skills

- ✓ Adaptability
- ✓ Teamwork.

QA Engineer | Junior

WP5

Edu: BSc in Computer Engineering

Exp: **1-2 Years** in Software Testing.

€ 2,500/mo

Key Responsibilities

- Execution of Stress Tests and Latency measurements.
- Verification of Non-Functional Requirements (<200ms).
- Bug tracking and reporting.

Technical Toolkit

Hard Skills

- ✓ **Tools**: Selenium, JMeter, Wireshark (Network Analysis).
- ✓ **Scripting**: Python (Automated testing).
- ✓ **Methodology**: TDD (Test Driven Development).

Soft Skills

- ✓ Detail-Oriented
- ✓ Testing mindset

System Integrator | Mid-Level

WP5

Edu: MSc in Automation

Exp: **3 Years** in Linux SysAdmin

€ 2,500/mo

Key Responsibilities

- Merging Hardware, AI, and Software modules.
- Deployment of the final prototype.
- Fault Tolerance verification.

Technical Toolkit

Hard Skills

- ✓ **OS**: Linux
- ✓ **CI/CD**: Jenkins, GitLab CI
- ✓ **Tools**: Bash, Virtualization.

Soft Skills

- ✓ Resilience under pressure
- ✓ Systemic Vision.

References

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  https://newsroom.aaa.com/2025/02/aaa-fear-in-self-driving-vehicles-persists/

- HMI Design for Anxiety Factor Analysis and Anxiety Relief Based on Field Tests (2024)
  https://aodr.org/xml/41432/41432.pdf

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- InvisibleEye: Mobile Eye Tracking Using Multiple Low-Resolution Cameras and Learning-Based Gaze Estimation (2017)
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- Going beyond Traditional SpO2 Measurement with Multiwavelength Optical Measurements (2023)
  https://www.ti.com/lit/ta/sszt538/sszt538.pdf?ts=1764538468980&ref_url=https%253A%252F%252Fwww.google.com%252F

Tools

flaticon

Vector Icons & Stickers Library

coolors

Palette & Color Scheme Generator