FINAL REPORT

Challenge@PoliTo – DESIGN OF A CONCEPT CAR NETWORKING SYSTEM IN THE DIGITALIZED MOBILITY WORLD

AUTONAV

1. SECTION: PERSONAL DATA

1.1. TEAM NAME: AUTONAV

1.2. PERSONAL TEAM DATA

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2. SECTION: DESCRIPTION OF THE PROBLEM

Autonomous vehicles are transforming urban mobility, offering safer and more convenient transportation options. Level 4 autonomous robotaxis have the potential to reduce reliance on personal vehicles while addressing challenges in safety and reliability in navigating complex environments such as intersections, tunnels, and pedestrian-dense areas. The challenge focuses on designing an optimized vehicle network system to improve the safety and reliability of autonomous mobility.

2.1. THE PROBLEM THAT THE CHALLENGE PROPOSES

The challenge focuses on developing a robust networking system for an autonomous RoboTaxi operating in urban environments. Key issues include:

- Navigating complex intersections and high-traffic areas.
- Ensuring continuous connectivity in GPS-denied environments such as tunnels.

- Detecting and responding to pedestrians and cyclists in busy areas.
- Enhancing vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication for safety and efficiency.

2.2. How the Problem Proposed is solved currently

Current autonomous vehicle solutions attempt to navigate these challenges through a combination of onboard sensors, such as traditional Lidar and Cameras for autonomous navigation, basic GPS repeaters in tunnels, predefined rule-based algorithms, and vehicle-to-everything (V2X) communication. However, each of these methods has its limitations:

- **Sensor fusion complexity:** Current solutions struggle with integrating multiple sensor inputs effectively, leading to inaccurate perception in complex scenarios.
- **Latency in decision-making:** AI models and communication networks introduce processing delays, which can be critical in high-speed environments.
- **Scalability of V2X infrastructure:** Many urban areas lack the necessary infrastructure to support large-scale V2X communication.

By tackling these specific gaps, our solution aims to provide a scalable, real-time decision-making framework that improves autonomous vehicle safety and efficiency in urban environments.

3. Section: Solution proposed by the team

3.1. Short description of the solution

Our proposed solution enhances autonomous vehicle navigation, in our case a Robotaxis navigation, using a hybrid sensor fusion approach, combining onboard sensors with offboard infrastructure data. We enhance decision-making through edge computing and AI-driven algorithms that process real-time information with minimal latency. Additionally, we propose alternative localization methods such as prebuilt high-resolution maps for tunnel navigation, ensuring seamless operation even in GPS-denied areas.

The vehicle continuously collects environmental data through FMCW lidar, radar, cameras, and ultrasonic sensors while exchanging information with infrastructure and other vehicles to optimize navigation. Edge computing enables fast data processing, reducing reliance on cloud connectivity. Modal Predictive Control (MPC) optimizes real-time vehicle movements to enhance efficiency and safety. In areas where GPS is unavailable, prebuilt maps ensure accurate localization, allowing the Robtaxi to operate reliably in tunnels and other challenging environments.

Our solutions focus on overcoming the three main challenges: pedestrian detection in urban areas, intersection navigation, and connectivity loss in tunnels.

3.2. TYPE OF SOLUTION

A product/device ☐ A system ☑ A processing method ☐

An algorithm ☑ Other ☐ (explain)

Comment and short motivation:

This solution enables Robotaxi to operate efficiently in complex urban environments, ensuring safer navigation, improved decision-making, and enhanced real-time connectivity.

3.3. APPLICATION AREAS OF THE SOLUTION

The solutions proposed for the autonomous Robotaxi system have various application areas across urban mobility, safety, and infrastructure integration. By addressing challenges such as sensor fusion, connectivity, and public acceptance, these advancements will enhance the overall efficiency of autonomous transportation. Given below are some of the key areas to implement these proposed solutions:

- Autonomous public transportation (Robotaxis).
- Smart cities and intelligent transportation systems.
- Fleet management for ride-sharing services.
- Logistics and goods transportation in urban areas.

3.4. ACCURATE DESCRIPTION OF THE SOLUTION

To ensure safe and reliable operation, the Robotaxi relies on a combination of onboard and offboard sensors. Onboard sensors, integrated within the vehicle, are designed to maintain optimal functionality under challenging conditions, leveraging advanced technologies for comprehensive awareness and precise decision-making. Offboard sensors, such as radar, and cameras and a V2X communication unit mounted on infrastructure like traffic lights, poles, and buildings, provide additional environmental data. This multi-layered fusion of onboard and offboard systems eliminates blind spots, enhances object detection, and ensures robust decision-making in various lighting and weather conditions, making autonomous operation more reliable and efficient.

3.4.1. On board Sensors

FMCW LiDAR:

A single Frequency-Modulated Continuous Wave (FMCW) Lidar unit is mounted on the roof, providing 360° coverage. This sensor serves as the primary tool for 3D mapping, object detection, and velocity estimation. Unlike traditional lidars, FMCW lidar utilizes Doppler shift to measure both distance and speed, offering improved performance in poor weather conditions and immunity to interference from other lidar systems. With its long range and high resolution, this sensor reduces the need for multiple lidar and radar units, enhancing cost efficiency.

Radar:

The radar system comprises four units: two long range radars positioned at the front and rear for detecting fast-moving objects at a distance, and two short-range radars on the sides for blind-spot monitoring. These radars complement the capabilities of the FMCW lidar by providing redundancy and enhanced situational awareness in high-speed and urban scenarios.

Cameras:

Five cameras are distributed across the vehicle to provide visual data for object classification, pedestrian recognition, and lane detection.A high-resolution camera is used for object and lane recognition, while side cameras are mounted on the mirrors for peripheral coverage and blind-spot monitoring. A rear camera aids in parking and obstacle detection, and an interior camera ensures passenger monitoring. This setup balances coverage and cost by minimizing redundancy while maintaining critical viewpoints.

Ultrasonic Sensors:

These sensors are specifically designed for low-speed maneuvers, such as parking and navigating tight urban spaces. Their precision enhances the vehicle's ability to operate safely in crowded environments.

The proposed sensor configuration leverages the strengths of each sensor type, with FMCW lidar providing long-range and high-resolution environmental mapping, supported by radar for redundancy and cameras for object recognition. Ultrasonic sensors address close-range detection requirements. This system not only enhances safety but also ensures cost effectiveness by minimizing sensor overlap. The inclusion of advanced technologies like 4D lidar further improves performance in adverse conditions, addressing key challenges in autonomous robotaxi deployment.

3.4.2.Offboard Sensors

Millimeter-Wave Radar:

Millimeter-wave radar, installed at strategic points like highway on-ramps and intersections, detects objects over long distances, even in low-visibility conditions. It complements other sensors by providing reliable data on the position and movement of obstacles, particularly in challenging weather.

Blind Spot Radar:

Blind spot radar sensors, located near merging lanes or turning lanes, help detect objects or vehicles hidden from the Robotaxi's direct line of sight. These sensors improve safety by enabling safe lane changes and navigation in congested or tight spaces.

Camera:

Cameras installed at intersections and pedestrian crosswalks capture visual data such as traffic signals, lane markings, and pedestrians. These cameras help the Robotaxi identify important elements like traffic lights and obstacles, aiding in real-time decision making, particularly in urban environments.

Communication Unit:

A V2X (Vehicle-to-Everything) communication unit is a critical component in intelligent transportation systems, enabling seamless data exchange between vehicles and their surroundings. It facilitates communication with other vehicles (V2V), infrastructure (V2I), pedestrians (V2P), and networks (V2N), enhancing road safety, traffic efficiency, and the overall driving experience. By integrating technologies such as Dedicated Short-Range Communication (DSRC) and Cellular V2X (C-V2X), the unit ensures reliable, low-latency communication essential for real-time decision-making. In infrastructure applications, V2X units embedded in traffic lights, road signs, and intersections provide vehicles with vital information about traffic conditions, road hazards, and signal changes, while also receiving data from vehicles to optimize urban mobility. This bidirectional exchange supports advanced driver-assistance systems (ADAS), autonomous driving, and cooperative traffic management, ultimately reducing congestion and improving road safety.

3.4.3.Data Processing

Offboard sensors play a crucial role in providing the vehicle with vital environmental information. To enable this, sensors are strategically installed in the surrounding infrastructure. These sensors collect real-time data about the road, traffic flow, and obstacles, offering the vehicle a more comprehensive understanding of its environment.

However, processing the enormous amounts of data generated by these sensors requires more than just hardware. **Edge computing** comes into play as a method for local, real-time data processing, reducing the need for distant cloud-based servers. These edge computing nodes are positioned close to the sensors themselves, often at intersections or other critical locations. By processing data right where it's captured, edge computing enables immediate decisions to be made, such as adjusting traffic signals or alerting vehicles about nearby hazards. This reduces latency, which is particularly important when milliseconds can make the difference between safe navigation and an accident.

The data gathered by these offboard sensors is not just processed locally, it is also shared with the vehicle to enhance its decision-making process. This is achieved through a dynamic **Traffic management system**. The system uses a network of sensors, edge computing nodes, and traffic signals to communicate with autonomous vehicles, sending real-time information about road conditions, traffic congestion, and other hazards. The vehicle can then incorporate this information into its own internal systems, creating a more accurate, up-to-date model of the environment.

3.4.4.Navigation and Control

Once the vehicle receives this data, it must integrate it with its onboard sensors. This fusion of onboard and offboard data is managed through a **Hybrid Fusion framework**. At the lowest level, raw data from lidar and radar is fused to create an accurate depth map of the surrounding environment, essential for obstacle detection. As the data moves up the fusion layers, object classification and pedestrian detection become more refined, aided by the integration of visual information from cameras.

This fused data is then fed into the vehicle's **Model Predictive Control (MPC)** system. MPC uses this information to calculate the best path for the vehicle in real time, considering factors such as obstacles, road geometry, and the vehicle's current state. For example, if a pedestrian is detected in the path, the system can adjust the vehicle's speed or steering to ensure a safe maneuver. The MPC continuously updates its decisions as new data is received, adapting to the ever-changing road conditions.

The beauty of this system lies in its feedback loop. As the vehicle moves, it constantly gathers data from its environment, updating its model and adjusting its path accordingly. If a new obstacle appears, for example, a vehicle suddenly merges into its lane, the vehicle can quickly adapt, ensuring a smooth and safe journey through the urban landscape.

By combining offboard sensor data, edge computing, hybrid sensor fusion, and MPC, autonomous vehicles can navigate complex environments with confidence. The continuous flow of information from both onboard and offboard sources enables real-time decision making, ensuring that these vehicles can react quickly to dynamic situations, ultimately improving safety, efficiency, and overall driving performance.

3.4.5.Connectivity Enhancements

V2X communication allows vehicles to exchange real-time information with other vehicles, infrastructure, and even pedestrians, enhancing road safety and improving traffic flow. Through **Vehicle-to-Vehicle (V2V)** communication, cars can share data on speed, position, and braking, helping prevent collisions and enabling smoother traffic coordination. Similarly, **Vehicle-to-Infrastructure (V2I)** communication allows vehicles to interact with traffic signals, roadside sensors, and other smart infrastructure to optimize traffic flow, reduce congestion, and improve decision-making at intersections.

One of the biggest advantages of V2X communication is that it extends a vehicle's perception beyond its onboard sensors, allowing it to anticipate potential hazards before they become visible. This real-time data sharing also improves decision-making in complex driving situations, such as navigating busy intersections or responding to emergency vehicles. Furthermore, V2X plays a crucial role in reducing traffic congestion by enabling vehicles and infrastructure to work together, dynamically adjusting traffic lights and vehicle movements to maintain smooth traffic flow. Ultimately, this technology enhances both safety and efficiency, paving the way for a more connected and intelligent transportation system.

3.4.6.GPS-Denied Navigation

In areas where GPS signals are unavailable or weak, such as tunnels or urban canyons, the vehicle relies on high-resolution prebuilt maps for accurate localization. These maps are created using a combination of detailed data sources such as LiDAR, radar, and high-definition cameras. The map-building process involves collecting precise environmental data to capture road geometry, landmarks, lane markings, elevation changes, and other critical features. This data is processed and fused to create a digital representation of the environment with centimeter-level accuracy.

Once the map is created, it is stored in the vehicle's system and continuously used for localization. As the vehicle moves through GPS-denied areas, it compares its real-time sensor data with the map, enabling it to track its position and maintain safe, reliable navigation. This solution ensures that even without real-time GPS input, the vehicle can accurately determine its location and navigate through challenging environments.

The system integrates **V2X communication**, **edge computing**, **high-resolution prebuilt maps**, and **model predictive control (MPC)** to ensure optimal navigation.

3.5. Additional description of possible particularly Innovative aspects of the Solution

As we described in the last section, we have:

- V2V and V2I communication for enhanced situational awareness and coordination.
- Edge computing for real-time processing without cloud latency.
- Prebuilt maps for accurate positioning in GPS-denied environments.
- Model Predictive Control (MPC) for dynamic vehicle path optimization.

3.6. Development status of the Solution

The current stage of development for the proposed Robotaxi solutions varies depending on the maturity of the underlying technologies.

Onboard and offboard sensor fusion, which integrates lidar, radar, cameras, and infrastructure-based sensors, is currently at TRL 6-7. This means the technology has been successfully demonstrated in real-world environments, but further optimization is needed to handle diverse conditions such as extreme weather, heavy traffic, and unexpected obstacles. With continued refinement of AI-driven sensor fusion models, this solution has the potential to reach TRL 9, where it can be fully deployed in commercial applications.

Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication is at TRL 6-7, as these technologies are already being tested in smart city environments. V2V communication allows vehicles to share data on speed, position, and road conditions, while V2I enables interaction with traffic signals and road sensors. The primary challenge lies in infrastructure deployment and standardization, as not all urban areas currently support these systems. With broader adoption and regulatory support, this solution could reach TRL 9, allowing seamless real-time traffic coordination between autonomous and human-driven vehicles.

In short, most of the Robotaxi's core technologies are between TRL 5-7, indicating they are in advanced development or early real-world trials. With further refinement, expanded testing, and regulatory support, these solutions have the potential to reach TRL 9, enabling full-scale deployment of autonomous taxi services in urban environments. However, progress will depend on overcoming technical challenges, improving AI reliability, and building public and legal acceptance.

4. Section: State of the Art and Comparable Solutions

4.1. Description of the known solutions present in Literature/ Papers

Paper Title	Authors	Brief description of the Paper	Differences with the Proposed Solution
Waymo's Autonomous Driving System	Alphabet Inc.	Uses advanced LiDAR, radar, and AI for navigation.	Does not emphasize infrastructure-based sensor fusion.
Tesla Autopilot	Tesla Inc.	Primarily vision-based AI for autonomous driving.	Relies less on external infrastructure data.
Real-time Model Predictive Control of Path Following for Autonomous Vehicles	W.Zhao,H.Wei,Q.Ai,N. Zheng,C.Lin,andY.Zhang	MPC approach for autonomous vehicle navigation.	Lacks integration with infrastructure-based data.

4.2. Prior Art - Existing Patents

(Search on web site: www.orbit.com or Google Patent or www.espacenet.com)

Patent Number	Brief Patent description	Differences with the Proposed Solution

4.3. Known Product

(Description of any products that have similarity, same functioning and/or final objective, compared to the proposed solution)

Product Name	Manufacturing Company	Brief description and features of the Product	Differences with the Proposed Solution
Orolia GPS Repeater	Orolia	GPS signal extension system.	Does not integrate prebuilt maps for navigation.

4.4. Any general Known Solution

(Description of any Solution that have similarity, same functioning and/or final objective, compared to the proposed solution)

- Edge computing for real-time processing in autonomous systems.
- V2X communication for intelligent transport networks.

5. Section: Challenge's Steps

5.1.DATA IDENTIFICATION

As part of the first step in this challenge, we conducted extensive research to analyze the existing barriers to the advancement, deployment, and widespread adoption of autonomous vehicles (AVs).

This analysis focused on identifying key gaps in five critical areas: energy efficiency, sensor technology, cybersecurity, data privacy, and infrastructure, fundamental aspects to ensuring the safety, reliability, and efficiency of autonomous mobility in an increasingly digitalized transportation ecosystem.

1. Energy Efficiency

One of the most pressing concerns for Level 4 autonomous vehicles is their energy consumption and environmental impact. While electric AVs promise to reduce emissions compared to traditional combustion-engine vehicles, the computational demands of autonomous driving introduce significant energy challenges.

- Computational Costs: AVs rely on powerful onboard processors to handle real-time perception, decision-making, and navigation tasks. A study by MIT predicts that the data processing needs of AVs will double every three years, leading to an exponential increase in energy consumption. If AV deployment reaches current global vehicle fleet levels, their combined energy consumption could exceed that of all existing data centers.
- Environmental Impact: Autonomous driving systems can increase greenhouse gas (GHG) emissions by 3-20% due to additional weight and the power required by AI-driven navigation and perception systems. Some AV processors consume up to 2,000 watts, which can negate the environmental benefits of electric vehicles.

To address these two main issues related to the energy efficiency of autonomous vehicles, we have identified the following solutions:

- Optimizing Hardware and Software:
  - Reducing the size and weight of LiDAR, cameras, and sensors can improve aerodynamics and energy efficiency.
  - Implementing eco-routing algorithms can optimize travel paths to minimize energy consumption.
  - Edge computing can shift computational tasks to off-board cloud servers, reducing the onboard processing load. However, this approach requires high-speed, low-latency communication networks such as 5G to avoid delays that could compromise safety.
- Renewable Energy Integration: Expanding the use of solar-powered and wind-powered charging stations can help reduce the carbon footprint of AV operations. Developing an efficient charging infrastructure is crucial, particularly for high-density urban environments.

2. Sensor Technologies

Autonomous vehicles rely on an array of sensors—including LiDAR, RADAR, and cameras—to perceive their environment. However, significant challenges remain in ensuring their accuracy, reliability, and cost-effectiveness.

- High Cost and Limited Coverage:
  - Creating high-definition (HD) maps for AV navigation is expensive and labor-intensive, requiring dedicated survey vehicles equipped with LiDAR.
  - LiDAR sensors often have a narrow field of view, making it difficult to interpret complex environments such as intersections and unstructured road areas.
- Data Processing and Bandwidth Constraints:
  - Real-time sensor data collection requires massive bandwidth for data transmission and processing. Traditional vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication networks struggle to handle the volume of sensor data efficiently.
  - Effective data compression and multi-sensor fusion techniques are needed to ensure seamless operation.
- Environmental Challenges:
  - Adverse weather conditions (rain, snow, fog) significantly degrade sensor accuracy. Cameras struggle in low-light conditions, and LiDAR performance is affected by reflective surfaces such as ice.
- Multi-Sensor Fusion Issues:
  - Current AV systems face difficulties in integrating and synchronizing data from LiDAR, RADAR, and cameras, particularly in challenging environments with fluctuating lighting conditions.
  - Sensor occlusion (e.g., temporary obstructions due to other vehicles or infrastructure) remains a significant limitation.

3. Cybersecurity

As AVs become increasingly reliant on digital communication and cloud-based software updates, cybersecurity emerges as a critical vulnerability. Without robust security measures, cyberattacks could compromise vehicle safety and operational integrity.

- Attack Vectors:
  - Camera Attacks: Adversarial techniques can trick AV vision systems (e.g., altering stop signs so they are misclassified as speed limit signs).
  - GPS Spoofing and Jamming: Attackers can manipulate AV navigation by feeding fake GPS signals, leading to route deviations or system failures.

- Remote Hacking: AVs rely on wireless communication channels (Wi-Fi, V2X, cellular networks), making them susceptible to remote hijacking of braking, acceleration, or steering functions.
- Phishing and User Exploitation: As AV systems integrate with personal devices (e.g., smartphones), traditional phishing attacks could target AV interfaces.

- Software Security and Update Challenges:
  - Many AVs use over-the-air (OTA) software updates, but there is no standardized framework to ensure the integrity of these updates and prevent unauthorized modifications.
  - Incident Response Mechanisms are lacking—there is no clear industry-standard protocol for responding to AV cyber incidents.
- Standardization Gaps:
  - The automotive industry currently lacks universally accepted cybersecurity standards, leading to inconsistent security practices across different manufacturers.

4. Data Privacy

AVs generate and process vast amounts of sensitive data, raising concerns about user privacy and regulatory compliance.

- User Data Collection Risks:
  - AVs track and store user information such as driving habits, frequent routes, and real-time location data.
  - Without proper encryption and consent mechanisms, this data could be exploited by third parties or malicious actors.
- Regulatory Uncertainty:
  - GDPR compliance in Europe mandates that AV companies provide users with meaningful explanations of how their data is collected, processed, and used. However, regulatory gaps remain regarding how long this data can be stored and who has access.
- Black-Box AI and Explainability Issues:
  - Many AV decision-making processes rely on deep learning models, which are often opaque and difficult to interpret.
  - There is an urgent need for user-friendly explainability tools that allow passengers and regulators to understand AV behavior in case of an incident.

5. Infrastructure

The deployment of autonomous vehicles requires significant upgrades to existing road and communication infrastructure.

- Lack of Dedicated AV Lanes:
  - Some regions, such as Michigan (USA) and Beijing (China), have introduced dedicated AV lanes, but widespread adoption remains limited.
  - Shared roadways with human-driven vehicles create unpredictable driving environments that challenge AV decision-making systems.
- Inconsistent Traffic Management Systems:
  - Current infrastructure does not provide real-time traffic data to AVs (e.g., accident reports, construction zones).
  - Integrating IoT-enabled traffic lights and smart road sensors could improve AV situational awareness.
- Weather-Resistant Road Infrastructure:
  - Most AVs struggle in adverse weather conditions due to poor road markings, inadequate sensor calibration, and lack of adaptive traffic control systems.
- High Implementation Costs:
  - Retrofitting cities with 5G networks, V2X infrastructure, and high-definition mapping technology requires substantial investment, particularly in developing regions where legacy traffic systems remain in place.

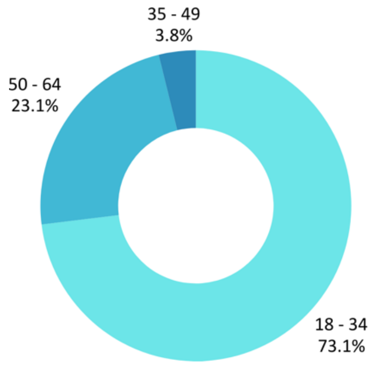
5.2. USERS' NEEDS ASSESSMENT AND SURVEY

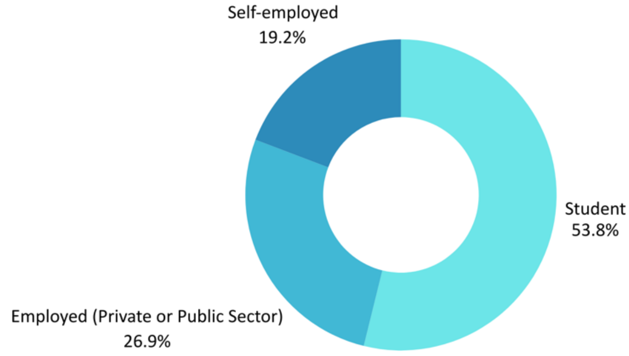
After identifying the main gaps concerning autonomous vehicles and their adoption, we narrowed our scope by focusing on a specific type of concept vehicle: the robotaxi. Subsequently, we created a questionnaire to understand both user preferences and the main issues that might make people more reluctant to use robotaxis.

Our questionnaire consisted of 30 questions with the specific goal of identifying the target user (age, gender, profession), their preferences, and their concerns, which became the challenges we aimed to address.

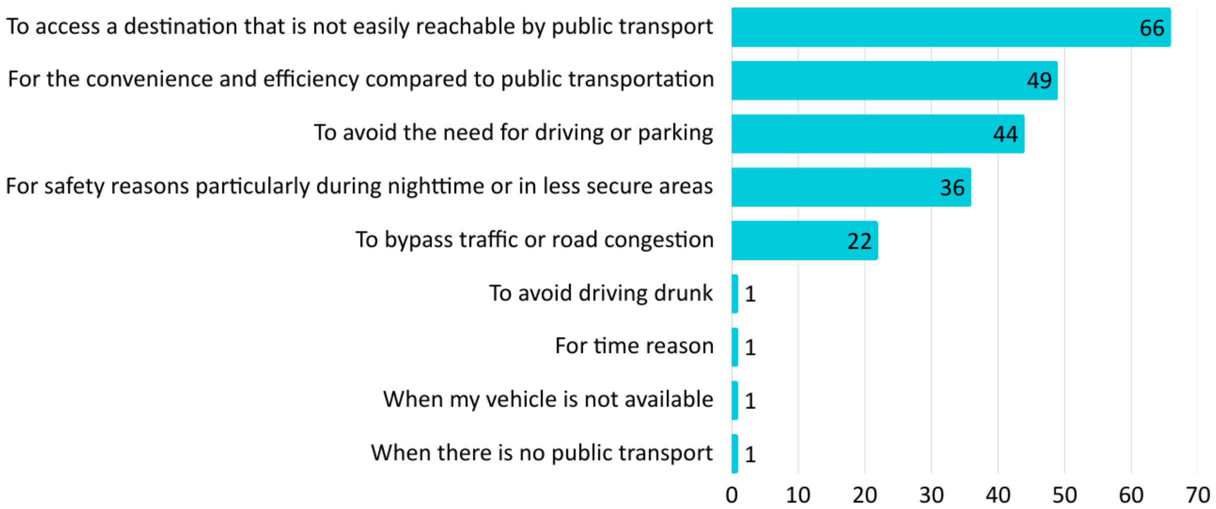
The analysis of demographic data revealed that our target user is between 18 and 34 years old, is self-employed, and primarily uses taxis for reasons related to comfort, avoiding the need to drive or search for parking, and reaching their destination without waiting for or walking to public transportation.

(Charts illustrating age distribution, occupation, and key reasons for using taxis)



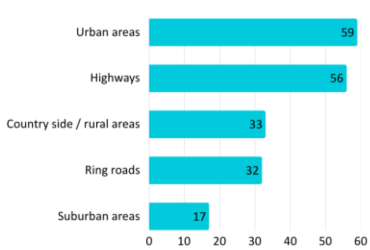


Which of the following reasons might lead you to take a taxi?

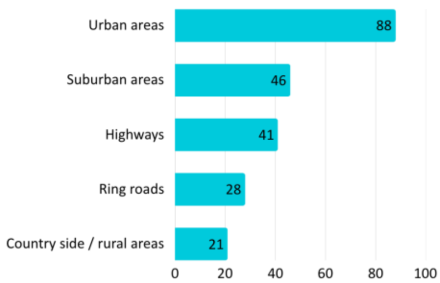


Different from urban public transportation, taxis can cover more demand scenarios than public transportation in terms of both time and space. Comfort is also why most people choose taxis instead of public transportation. Looking forward to the autonomous car network in 2030, Robotaxi may become an important shared transportation mode in cities.

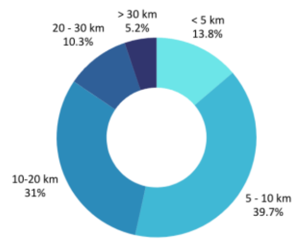
Which of the following contexts do you consider to be the most risky for the use of a Robotaxi?



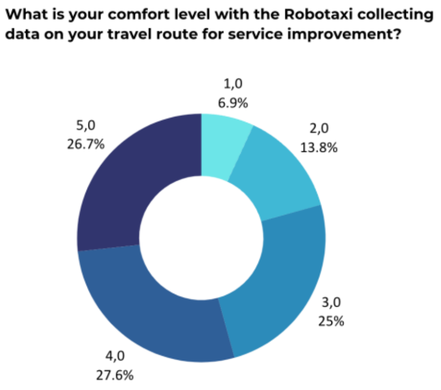
In which contexts do you think traveling in a Robotaxi could be useful?

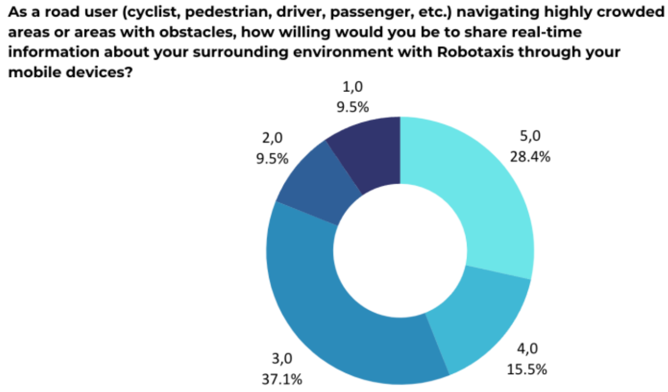


For which of the following distances would you consider using a taxi?

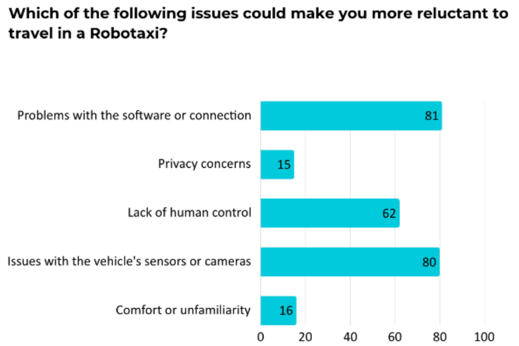


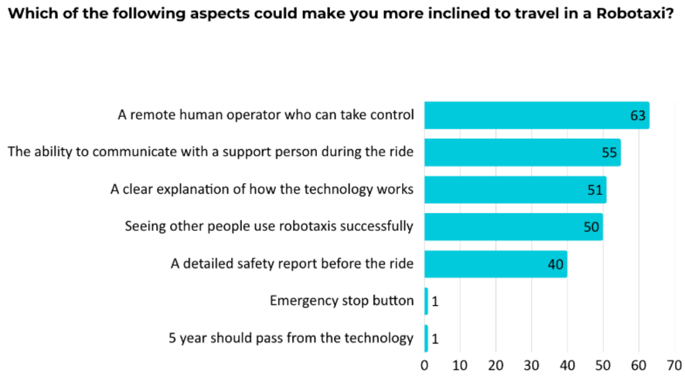
We found out that urban areas are always the centre of the topic when comes to Robotaxi. On the one hand, most people prefer to use Robotaxi in urban areas and thus it is considered the most important operating area of the Robotaxi. On the other hand, the concerns about the safety also stress on the urban areas in which traffic conditions are complex and accidents often have huge impacts.





Regarding data sharing, we considered 2 groups of people, the clients of Robotaxi and the other road users as Robotaxi as a product involves an extreme number of stakeholders. in general, the survey shows that the willingness to share data to ensure security is rather higher, which of course, needs a comprehensive detail of the regulation about the data processing.





Finally, some concerns about Robotaxi give us a clue of which possible problems to address for fully autonomous networking. Among them we identified several key points which includes reliable sensors, adaptive Models, good HMI system, Connectivity, etc.

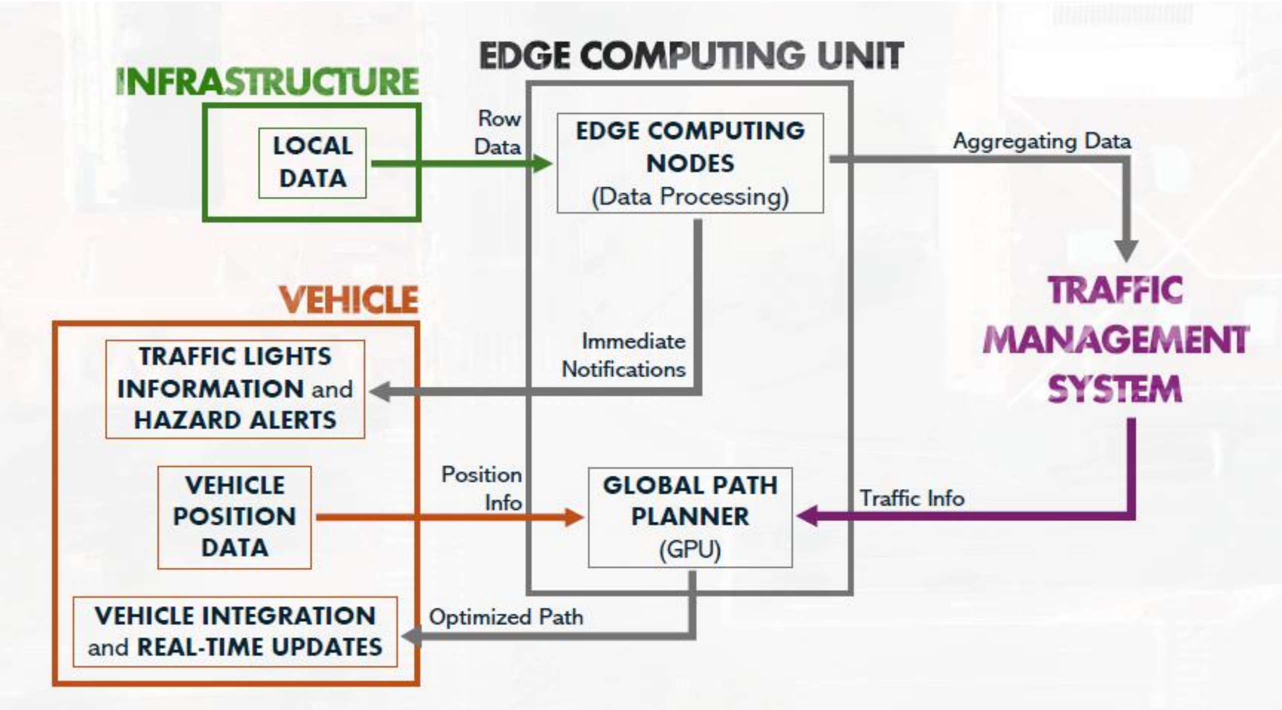
5.3. USE CASE AND FINAL SOLUTION

1. PORTA NUOVA

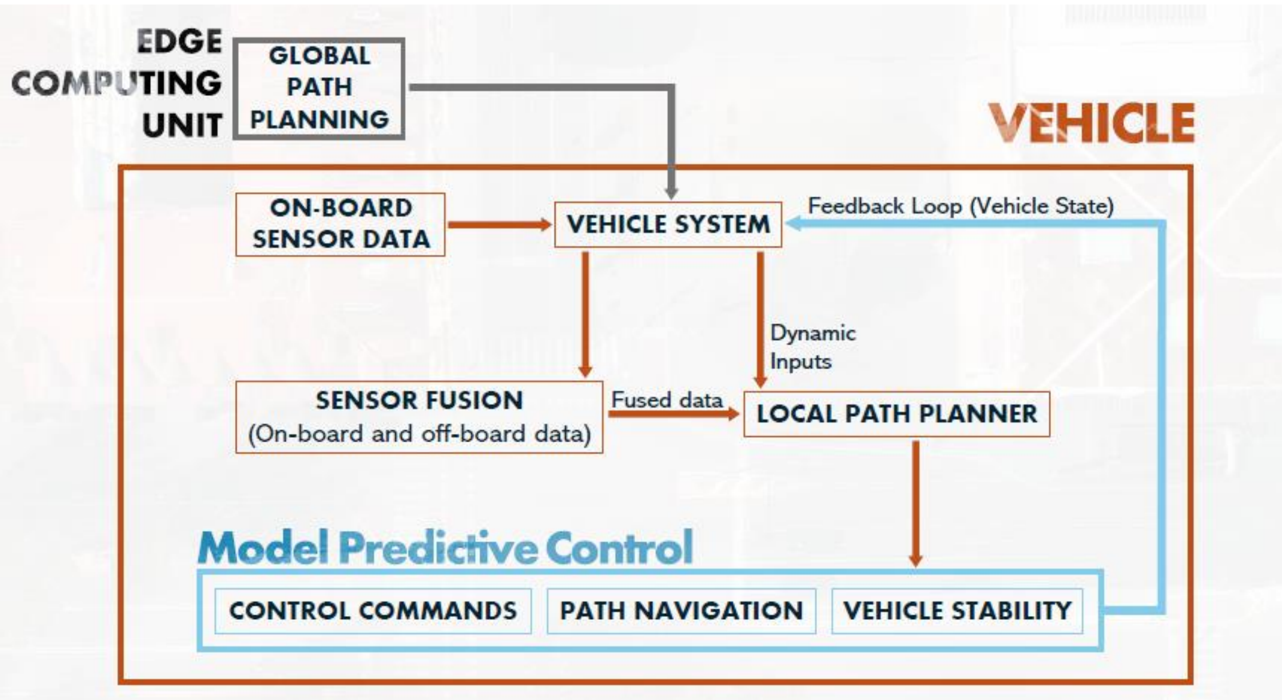
In the busy Porta Nuova area, we focus on addressing the challenges related to bicycles and pedestrians. These road users can behave unpredictably, making it crucial for the autonomous vehicle to accurately detect and respond to them in real-time.

To achieve this, the vehicle relies on a combination of onboard sensors, such as lidar, radar, cameras, and ultrasonic sensors, to monitor its surroundings. They are designed to maintain optimal functionality under challenging conditions, leveraging advanced technologies for comprehensive awareness and precise decision-making. These sensors provide detailed data on the positions and movements of bicycles and pedestrians.

In addition, embedded sensors in the infrastructure, such as smart traffic lights and road sensors, collect data about pedestrian crossings and bicycle paths. This information is transmitted to the vehicle through infrastructure-to-vehicle (I2V) communication, allowing it to anticipate and respond to potential hazards even beyond its direct line of sight. By integrating data from both onboard and infrastructure sensors through sensor fusion, the vehicle can make safe, informed decisions, enhancing safety for all road users in the Porta Nuova area.



Edge Computing Unit - Infrastructure



Modal Predictive Control (MPC)- Vehicle Integration

2. INTERSECTION

At intersections, vehicles often attempt to pass or change lanes, creating dangerous situations. The risk increases when emergency vehicles are present, as they need to navigate through traffic without stopping at traffic signals. To ensure the safety of passengers, the Robotaxi must receive real-time information about other vehicles intentions and the presence of emergency vehicles. The infrastructure around the intersection should be equipped to provide this data and relay it to the Robotaxi, enabling it to make informed decisions. This ensures that the Robotaxi can respond appropriately to avoid accidents, prioritize the passage of emergency vehicles, and maintain safe traffic flow.

For the solution to ensure safe and effective operation in dynamic traffic environments, we propose utilizing both onboard and offboard sensors, processed by advanced algorithms. In our scenario, offboard sensors will provide critical data about the traffic environment, including information on nearby vehicles, pedestrians, and other road users. This data is transmitted through traffic control management systems, which relay information about road conditions, intersection statuses, and approaching emergency vehicles. Onboard sensors, such as cameras, lidar, and radar, will complement this data by offering real-time perception of the immediate surroundings of the robotaxi. Together, the integration of offboard and onboard sensors allows the vehicle to have a comprehensive understanding of its environment, facilitating better decision-making in complex traffic situations.

The core of this system relies on a combination of Edge computing Unit and Traffic Managment system and Communication Unit (V2X) to process this data and make intelligent decisions.

3. TUNNEL

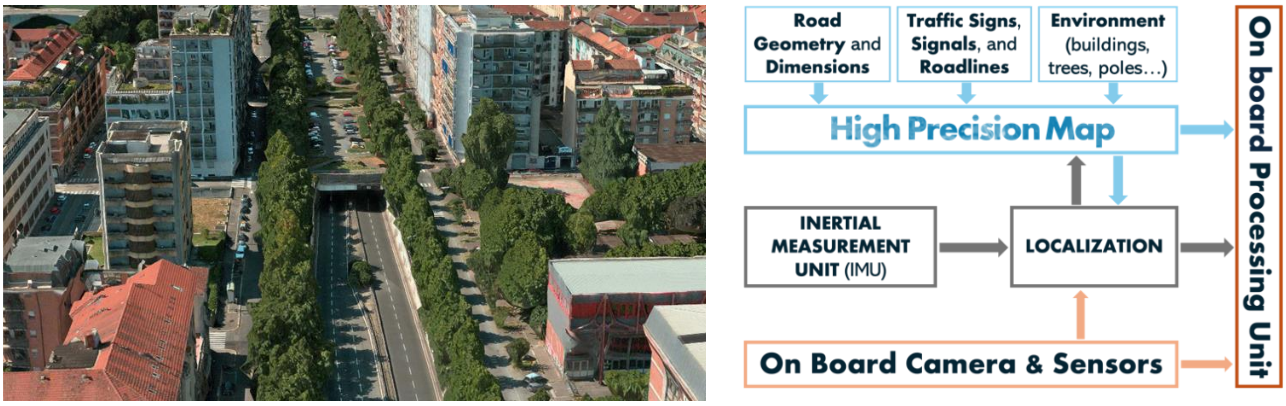
Connectivity Issues

A significant challenge inside tunnels is the lack of connectivity, which affects both drivers and automated systems. Weak network signals prevent real-time navigation updates and communication, making it difficult for drivers to receive assistance or for autonomous vehicles to operate efficiently. Additionally, emergency response coordination may be delayed due to signal disruptions. A viable solution involves integrating high-precision maps with on-board processing units, ensuring continuous localization without relying on external connectivity. Technologies such as inertial measurement units (IMU) and on-board cameras & sensors can enhance positioning accuracy, allowing vehicles to navigate seamlessly.

Illumination Challenges

Tunnel environments rely heavily on artificial lighting, which can cause direct glare transitions at entry and exit points, momentarily impairing visibility. However, advanced onboard sensors like LiDAR and high-resolution cameras can function effectively even in low-light or poor visibility conditions. LiDAR, in particular, enables vehicles to detect obstacles, road geometry, and traffic signs regardless of illumination. When combined with high-precision mapping and adaptive lighting systems, these technologies ensure safe and smooth transitions, reducing accident risks.

By leveraging these solutions, vehicles can navigate tunnels efficiently, overcoming connectivity limitations and ensuring reliable performance in challenging lighting conditions.



High Precision Map

5.4. Definition of Value Proposition of Proposed Solution

The value proposition of the proposed robotaxi solution lies in its ability to provide a safer, more efficient, and cost-effective transportation option through the integration of advanced sensor fusion, real-time decision-making, and cutting-edge technologies like Model Predictive Control (MPC) and Traffic Managment System and high precision Maps. By focusing on lidar, radar, cameras, and ultrasonic sensors, the solution ensures robust performance in diverse driving conditions. The system is designed to address critical challenges such as loss of connectivity in tunnels, pedestrian detection, unpredictable bicycle movements, and complex intersection navigation. Through enhanced safety features, seamless communication between the vehicle and infrastructure, and continuous optimization of vehicle control, this solution improves traffic flow, reduces accidents, and creates a more responsive and intelligent transportation network. Ultimately, it enhances the user experience by delivering a reliable and futuristic transportation solution that paves the way for the next generation of autonomous vehicles.

6. Section: Future Developments

6.1. Possible Future Developments

The future for the autonomous Robotaxi system focuses on enhancing safety, efficiency, and public acceptance. A key priority is improving sensor fusion by integrating advanced algorithms that combine onboard and offboard data more effectively. This will enable the Robotaxi to make real-time decisions with greater accuracy, particularly in dynamic urban settings where pedestrians, cyclists, and other vehicles create unpredictable scenarios. Additionally, artificial intelligence and machine learning advancements, particularly in Deep Reinforcement Learning (DRL), will allow the Robotaxi to adapt to changing traffic conditions. The Hybrid Motion Planning Framework (HMPF) will also be refined to improve path optimization and obstacle avoidance.

- Improved AI-driven sensor fusion for real-time decision-making
- Refinement of DRL models for enhanced traffic adaptation

- Optimization of the Hybrid Motion Planning Framework (HMPF)

Infrastructure integration and connectivity will also be a major area of development. Expanding Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication will allow the Robotaxi to interact seamlessly with traffic signals and emergency vehicles, ensuring smoother navigation. Additionally, edge computing will be deployed at key traffic points such as intersections and tunnels, enabling faster real-time processing of environmental data to reduce latency and improve safety.

- Expansion of V2V and V2I communication for better coordination
- Deployment of edge computing for real-time processing at intersections and tunnels

For tunnel navigation, the focus will be on ensuring continuous connectivity in GPS-denied environments. This will be achieved by implementing intelligent GPS repeater systems and exploring alternative localization technologies such as LiDAR-based positioning and AI-driven 3D mapping. These solutions will enhance positioning accuracy and reliability, ensuring that the Robotaxi can navigate tunnels and other enclosed spaces without disruption.

- Implementation of intelligent GPS repeater systems in tunnels
- Exploration of LiDAR-based positioning and AI-driven 3D mapping

Safety will be reinforced through redundancy in AI decision-making and fail-safe mechanisms to handle unexpected system failures. Extensive real-world testing will validate these safety features before large-scale deployment. Ensuring robust security protocols will also be essential in protecting vehicle data and communication networks from cyber threats.

- Redundancy in AI decision-making to enhance safety
- Fail-safe mechanisms for handling system failures
- Real-world testing to validate performance in diverse conditions

Public acceptance will play a crucial role in the success of Robotaxi adoption. To address user concerns, large-scale surveys will be conducted to gather feedback, and educational campaigns will help familiarize the public with autonomous vehicle benefits and safety measures. Transparent communication about the technology's reliability and effectiveness will be key to building trust.

- Large-scale public surveys to assess concerns and expectations
- Educational campaigns to improve public awareness and trust

To transition from research to real-world application, pilot programs will be launched in select urban areas with high vehicle and pedestrian density. These programs will serve as a testing ground to refine the technology, ensure compliance with regulatory standards, and optimize the user experience. The long-term goal is to scale the Robotaxi service for widespread commercial deployment by 2030, ensuring cost efficiency and sustainability in production and operation.

- Pilot programs in urban environments for real-world testing
- Collaboration with regulators to refine autonomous vehicle policies

- Scaling up for commercial deployment by 2030 with cost optimization strategies
- Improved AI-driven sensor fusion for real-time decision-making

6.2. Interests of the Team in Continuing Development

(Describe any interest of the team or its teammates in continuing the development of the Solution. Ex: Thesis, personal interest, etc., etc.)

We, **Parisa Ghasaban Khorasgani, and Mudumbai Anirudh Badrinath,** are eager to continue developing this solution, exploring thesis opportunities in autonomous vehicle communication and real-time data exchange. We are also interested in industry collaboration for real-world testing and researching edge computing to enhance system responsiveness. With a strong passion for innovation, we aim to contribute to advancing autonomous mobility through research and practical applications.

DATA PROCESSING

Data processing is authorized according to General Data Protection Regulation (EU) 2016/679 (GDPR) for the purposes contained in this application.

Date 31/01/2025

SIGNATURE OF EACH TEAM MEMBER

(Name, Surname and relative signature)

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