Autonomous

COST REPORT

Abstract

This cost report for the Autonomous Track presents a comprehensive analysis and estimation of the expenses involved in developing a fully autonomous system for electric vehicles. The primary goal of this event is to enable self-driving capabilities while ensuring cost-effective and efficient implementation, manufacturing, and integration of each system component.

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Introduction

The advent of autonomous vehicles heralds a new era in transportation, promising enhanced safety, efficiency, and convenience. The Autonomous Track Cost Event focuses on the detailed financial analysis and cost estimation required for developing a fully autonomous system specifically designed for electric vehicles. This event not only emphasizes the implementation and integration of cutting-edge technology but also stresses the importance of cost-effectiveness throughout the process.

The goal of this report is to provide a thorough understanding of the costs associated with the development and deployment of autonomous vehicle systems. It covers every aspect, from the selection and integration of sensors to the manufacturing of mechanical components, the validation of the system's performance, and the safety measures essential for reliable operation. Each section is meticulously detailed, offering insight into the financial implications of each component and process involved.

This report is divided into five primary sections: Sensor and Material Selection, Mechanical Fixation, Validation, Safety Measures, and Cost of Working Hours. Each section includes a Bill of Materials (BOM) and a detailed cost analysis, ensuring a comprehensive understanding of the financial requirements. By providing these insights, the report aims to support the development of autonomous systems that are not only technologically advanced but also economically viable.

Sensors and material selection

This section outlines the cost analysis and specifications for each sensor used in the autonomous system. Each sensor is described with its type, specifications, price, function, and mechanical fixation details.

1. LIDAR: Velodyne LiDAR VLP-16 Puck 3D - Real Time - LiDAR

Figure 1Velodyne LiDAR

- **Specifications:**
    1. 360 Degree Horizontal Field of View
    2. 40 Degree Vertical Field of View
    3. 200m Range
    4. Accuracy: +/- 3cm
    5. 20 Hz Max Frame Rate
    6. 16 Channels of Resolution
- **Price:** US $399.99
- **Function:** Ranging, mapping, and security
- **Mechanical Fixation:**
    - Mounted on top of the vehicle using a custom bracket for a stable platform and minimized vibrations.
    - Ensures a 360-degree horizontal field of view.

2. Cliff Sensor: Sharp GP2Y0A51SK0F

Figure 2 Cliff Sensor

- **Specifications:**
    1. Distance Measuring Range: 2 to 15 cm
    2. Analog Output Type
    3. United with PSD, Infrared LED, and Signal Processing Circuit
    4. Measuring Cycle: 16.5ms
- **Price:** US $9.99
- **Function:** Measuring the distance from the vehicle to the ground
- **Mechanical Fixation:**
    - Mounted on the front and rear bumpers at a low height.
    - Protected by a plastic housing to shield from debris.

3. Bumper Sensor: Car Reverse Parking Sensor Audio Buzzer

Figure 3Bumper Sensor

- **Function:** Audio Buzzer Alarm
- **Price:** US $11.95
- **Mechanical Fixation:**
    - Integrated into the front and rear bumpers.
    - Flush-mounted with the bumper surface to maintain aesthetics.
    - Encased in a weatherproof housing.

4. Wheel Encoders: E40S6-100-3-T-24 AUTONICS Incremental Encoder

Figure 4Wheel Encoders

- **Specifications:**
    1. Resolution: 100 imp/rev
    2. Output Configuration: Push/Pull
    3. Switching Frequency Max: 300kHz
    4. Supply Voltage: 12:24 V DC
- **Price:** US $76.50
- **Mechanical Fixation:**
    - Attached to each wheel hub.
    - Mounted with a secure bracket to prevent movement.
    - Encased in a protective cover.

5. IMU: VN-100 Rugged IMU/AHRS

Figure 5 IMU

- **Description:** High-performance Inertial Measurement Unit (IMU) and Attitude Heading Reference System (AHRS)
- **Specifications:**
    1. Combines 3-axis accelerometers
    2. 3-axis gyros
    3. 3-axis magnetic sensors
    4. 32-bit processor
- **Price:** US $950
- **Mechanical Fixation:**
    - Mounted centrally within the vehicle for balanced measurement.
    - Enclosed in a rugged, vibration-damping housing.
    - Positioned away from electronic interference sources.

6. Radar & GPS: Car Automotive Radar & GPS

Figure 6 Radar

- **Type:** Car Automotive Radar & GPS
- **Specifications:**
    1. Combined radar and GPS functionality
    2. Frequency range: 24-24.25 GHz
    3. Range: 0.2-200 meters for radar
    4. GPS Accuracy: +/- 1 meter
    5. Operating temperature: -40 to 85°C
    6. Power supply: 12V DC
- **Price:** US $10.36
- **Function:** Provides location data and obstacle detection
- **Mechanical Fixation:**
    - Mounted on the vehicle's roof or front bumper
    - Securely attached to avoid movement and ensure accurate data collection
    - Weatherproof housing for protection against environmental factors

7. Camera: Intel RealSense Depth Camera D435

- **Type:** Intel RealSense Depth Camera D435
- **Specifications:**
  1. Depth Technology: Stereo
  2. Depth Field of View (FOV): 85.2° × 58° × 95°
  3. Depth Resolution: Up to 1280 × 720
  4. Frame Rate: Up to 90 FPS
  5. RGB Sensor Resolution: 1920 × 1080
  6. Interface: USB 3.1 Gen 1
- **Price:** US $314.00
- **Function:** Captures 3D depth information and high-resolution color images
- **Mechanical Fixation:**
  - Mounted on the front or top of the vehicle for optimal field of view
  - Secured with an adjustable bracket for precise alignment
  - Protected by a weather-resistant casing

Figure 7 Intel RealSense Depth Camera

Sensor	Description	Price (USD)	Quantity	Total cost (USD)
LIDAR	Velodyne LiDAR VLP-16 Puck 3D - Real Time - LiDAR	399.99	2	799.98
Cliff sensor	Sharp GP2Y0A51SK0F	9.99	4	39.96
Bumper sensor	Car Reverse Parking Sensor Audio Buzzer	2.9875	4	11.95
Wheel encoder	E40S6-100-3-T-24 AUTONICS Incremental Encoder	76.50	5	382.50
IMU	VN-100 Rugged IMU/AHRS	950.00	1	950.00
Radar& GPS	Car Automotive Radar & GPS	10.36	5	51.80
Camera	Intel RealSense Depth Camera D435	314.00	1	314
Total				2,622.58

This table includes the part description, unit price, quantity used, and total cost for each sensor, resulting in a total cost of $2,622.58 for the sensor components.

Mechanical Fixation

Mechanical Fixation Report for Sensors and Components in the Vehicle

1. LiDAR Sensor

Model: Velodyne VLP-16

Fixation Process:

- Design:
  - Mounting Bracket: Design a cylindrical mount for the LiDAR sensor to ensure stable and secure placement on the vehicle's roof or front.
- Manufacturing:
  - CNC Milling: Produce the mounting bracket using CNC milling to achieve precise dimensions.
  - Surface Finishing: Anodize the aluminum to enhance corrosion resistance and durability.
- Assembly:
  - Positioning: Attach the mount to the roof or front of the vehicle where the sensor has a clear 360-degree field of view.
  - Fastening: Secure the LiDAR sensor to the mount using stainless steel screws (M4) and bolts (M6).
- Materials:
  - Mounting Bracket: Aluminum
  - Fasteners: Stainless steel screws (M4), bolts (M6), washers

2. GPS Antenna

Model: Custom GPS Antenna

Fixation Process:

- Design:
  - Mounting Pole: Design a vertical pole mount for the GPS antenna to ensure it is elevated and unobstructed.
- Manufacturing:
  - CNC Milling or Composite Molding: Create the pole using CNC milling for aluminum or molding techniques for fiberglass.
  - Surface Finishing: Anodize aluminum or coat fiberglass with protective resin.
- Assembly:
  - Positioning: Mount the GPS antenna on the roof of the vehicle, ensuring an unobstructed view of the sky.
  - Fastening: Attach the antenna to the pole using stainless steel screws (M4) and bolts (M6).
- Materials:
  - Mounting Pole: Aluminum or fiberglass
  - Fasteners: Stainless steel screws (M4), bolts (M6), washers.

3. Camera

Model: Intel RealSense D435

Fixation Process:

- Design:
  - Mounting Bracket: Create a custom mount for the camera, allowing for adjustments in angle and orientation.
- Manufacturing:
  - CNC Milling or 3D Printing: Produce the mounting bracket using CNC milling for aluminum or 3D printing for ABS plastic.
  - Surface Finishing: Anodize the aluminum mount or smooth the 3D-printed plastic for durability.
- Assembly:
  - Positioning: Mount the camera on the front or rear of the vehicle, ensuring a clear field of view.
  - Fastening: Secure the camera to the bracket using stainless steel screws (M4) and bolts (M6).
- Materials:
  - Mounting Bracket: Aluminum or ABS plastic
  - Fasteners: Stainless steel screws (M4), bolts (M6), washers

4. IMU (Inertial Measurement Unit)

Model: Custom IMU

Fixation Process:

- Design:
  - Mounting Plate: Design a flat plate to securely attach the IMU within the vehicle.
- Manufacturing:
  - CNC Milling: Create the mounting plate using CNC milling for precise dimensions.
  - Surface Finishing: Anodize the aluminum to prevent corrosion.
- Assembly:
  - Positioning: Mount the IMU inside the vehicle's chassis, ideally near the center of mass to accurately capture motion data.
  - Fastening: Secure the IMU to the plate using stainless steel screws (M3) and bolts (M4).
- Materials:
  - Mounting Plate: Aluminum
  - Fasteners: Stainless steel screws (M3), bolts (M4), washers

5. Cliff Sensors

Model: Custom Cliff Sensors

Fixation Process:

- Design:
  - Sensor Mounts: Design small mounts for each cliff sensor to attach them around the vehicle’s perimeter.
- Manufacturing:
  - 3D Printing: Produce the sensor mounts using 3D printing for accurate shapes and sizes.

- Surface Finishing: Smooth the 3D-printed parts for a clean finish.
- Assembly:
  - Positioning: Place the sensors at strategic locations around the vehicle's perimeter to detect edges and drop-offs.
  - Fastening: Attach the sensors to the mounts using plastic screws (M2) and bolts (M3).
- Materials:
  - Sensor Mounts: ABS plastic
  - Fasteners: Plastic screws (M2), bolts (M3)

6. Bumper Sensors

Model: Custom Bumper Sensors

Fixation Process:

- Design:
  - Sensor Housing: Create a robust housing to protect the bumper sensors from impact.
- Manufacturing:
  - 3D Printing or Molding: Produce the sensor housing using 3D printing or rubber molding techniques.
  - Surface Finishing: Smooth the 3D-printed parts or finish the rubber housing for durability.
- Assembly:
  - Positioning: Mount the sensors inside the bumper of the vehicle, ensuring they are well-protected and functional.
  - Fastening: Secure the sensors inside the housing using plastic screws (M2) and bolts (M3).
- Materials:
  - Sensor Housing: ABS plastic or rubber
  - Fasteners: Plastic screws (M2), bolts (M3)

Placement Summary

LiDAR Sensor: Mounted on the roof or front of the vehicle for a clear 360-degree field of view.

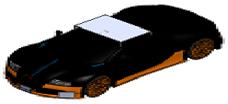
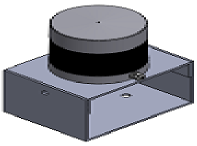
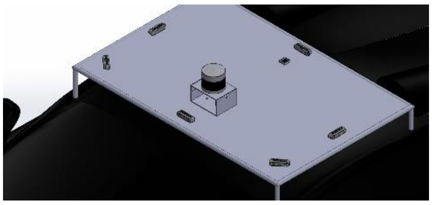
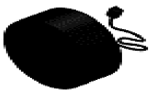
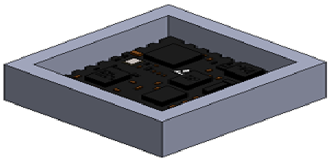
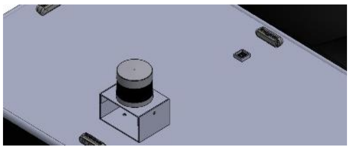
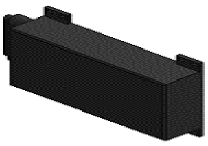
GPS Antenna: Mounted on the roof for unobstructed sky view.

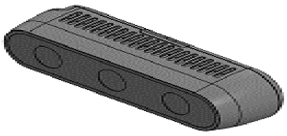
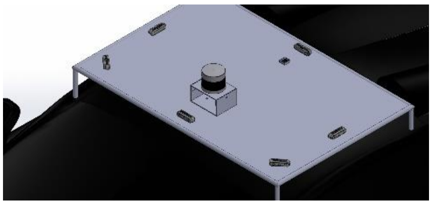
Camera: Positioned on the front or rear of the vehicle for optimal visual capture.

IMU: Placed near the vehicle's center of mass for accurate motion data.

Cliff Sensors: Distributed around the vehicle's perimeter to detect edges and drop-offs.

Bumper Sensors: Integrated within the vehicle's bumper for impact detection and protection.

Part	Part Name	Fixation
	Autonomous car	
	LIDAR	
	GPS	
	Bumper sensor	Integrated within the vehicle’s bumper for impact detection and protection
	Wheel encoder	Integrated on the four wheels of the vehicle
	VN-100SMD IMU	
	Radar	

	Intel RealSense Depth Camera D435	

Cost of validation

1. **Simulation and Real-World Testing Costs**

Simulation:

- **Simulator Software License:** $50,000
- **Hardware for Running Simulations**: $20,000
- **Personnel (Developers, Testers):** $100,000
- **Simulation Platforms: MATLAB/Simulink, CoppeliaSim, ROS, Visual Studio**
- **Hardware Prototype Car Costs:** $17,968.19

Total Simulation Cost: $187,968.19

Real-World Testing:

- **Vehicle and Equipment:** $200,000
- **Test Track Rental:** $30,000
- **Safety Personnel and Equipment:** $50,000

Total Real-World Testing Cost: $280,000

Total Cost of Validation: $467,968.19

2. **Justification and Mitigation of Disadvantages**

Simulation:

- Provides a safe, controlled, and cost-effective environment for early-stage testing, minimizing the risks associated with real-world testing.
- The use of MATLAB/Simulink, CoppeliaSim, ROS, and Visual Studio ensures high accuracy and reliability in modeling and testing the autonomous system.
- CoppeliaSim offers advanced simulation capabilities, enhancing the realism of the virtual testing environment.
- ROS provides robust tools for robot software development and integration, facilitating seamless communication between different system components.
- Visual Studio offers a powerful development environment, supporting efficient code development and debugging.

The hardware prototype car, costing $17,968.19, is crucial for bridging the gap between virtual and physical testing, contributing to the overall simulation costs.

Real-World Testing:

- Essential for final validation to ensure performance under actual conditions.
- Validates the system's performance, robustness, and safety in a variety of scenarios and environments.
- Combining simulation and real-world testing ensures comprehensive validation, leveraging the strengths of each approach to mitigate their individual disadvantages.

By combining simulation with MATLAB/Simulink, CoppeliaSim, ROS, and Visual Studio, and real-world testing, the validation process is thorough and reliable. This approach ensures that the autonomous system performs optimally in both controlled and real-world conditions, mitigating the risks associated with each method and providing a well-rounded validation strategy.

Safety measures

Ensuring the safety of both passengers and other road users is paramount in the development and deployment of autonomous vehicles. The following safety measures outline the systems and strategies implemented to achieve optimal safety performance. This includes software systems for operational management, communication protocols for vehicle interactions, sensor integration for cohesive data interpretation, and the central computing unit for overall system control.

1. System Software

OSEK

OSEK (Offene Systeme und deren Schnittstellen für die Elektronik im Kraftfahrzeug) is an automotive operating system designed to manage real-time tasks in microcontroller environments. It is widely used by automotive companies to coordinate operations between sensors and other vehicle components. The software plays a crucial role in identifying and reporting system issues, ensuring timely responses to any detected faults.

- **Function:** Manages operations between sensors and microcontrollers
- **Cost:** Licensing fees apply, typically negotiated per project
- **Key Features:**
    - Real-time task management
    - Fault detection and reporting
    - High reliability and industry standard compliance

2. Vehicle-to-Vehicle Communication (V2V)

V2V communication systems enable vehicles to exchange information about their speed, position, and direction. This technology enhances safety by allowing vehicles to communicate and coordinate actions such as speed adjustments, which helps prevent collisions and improve traffic flow.

- **Function:** Enables communication between nearby vehicles for coordinated actions
- **Cost:** Varies based on implementation and hardware requirements
- **Key Features:**
    - Real-time data exchange between vehicles
    - Coordination of speed and movement to avoid collisions
    - Utilizes microcontroller technology

Sensor Fusion

Sensor fusion technology integrates data from various sensors to create a comprehensive understanding of the vehicle's environment. This process ensures that the system can accurately interpret and respond to real-world conditions, enhancing the reliability and safety of the autonomous vehicle.

- **Function:** Integrates data from multiple sensors to provide a unified environmental understanding
- **Cost:** Dependent on the complexity of the sensor network and processing requirements
- **Key Features:**
    - Data integration from LIDAR, cameras, radar, etc.
    - Improved accuracy in object detection and environmental mapping
    - Can be implemented using ROS (Robot Operating System)

Robot Operating System (ROS)

ROS is an open-source framework used to develop software for robotic applications. In the context of autonomous vehicles, ROS is employed on mini computers such as Raspberry Pi or Jetson Nano to manage sensor data, perform calculations, and control vehicle functions.

- **Function:** Framework for developing and managing autonomous vehicle software
- **Cost:** Open-source (free), though hardware costs apply
- **Key Features:**
    - Flexibility and scalability
    - Comprehensive libraries for various robotic functions
    - Real-time data processing and control

Central Computer

The central computer is the core processing unit of the autonomous vehicle, responsible for overseeing and coordinating all vehicle functions. It processes data from sensors, executes control algorithms, and ensures overall system integrity. Any detected faults or errors in the system are reported and addressed by the central computer.

- **Function:** Central control unit for the vehicle's autonomous operations
- **Cost:** Varies based on specifications and capabilities (e.g., processing power, memory)
- **Key Features:**
    - High-performance processing for real-time data analysis
    - Integration with all vehicle sensors and subsystems
    - Fault detection and error management

Component	Description	Unit Price (USD)	Quantity	Total cost (USD)
Arm black pill	Operating system for microcontroller	9	1	9
Jeston nano 8 gb	Vehicle-to-Vehicle communication system	499	1	499
Sensor Fusion	Integration of sensor data (using ROS)	Open-source	1	Free
ESP8266 development board	low-cost Wi-Fi microcontroller, with built-in TCP/IP networking software, and microcontroller capability	7	1	7

Total Cost of the Car

Total Cost of the Car = Total System Cost + Car Parts

- Total Cost of the Car = $14,021.35 + $12,616.37

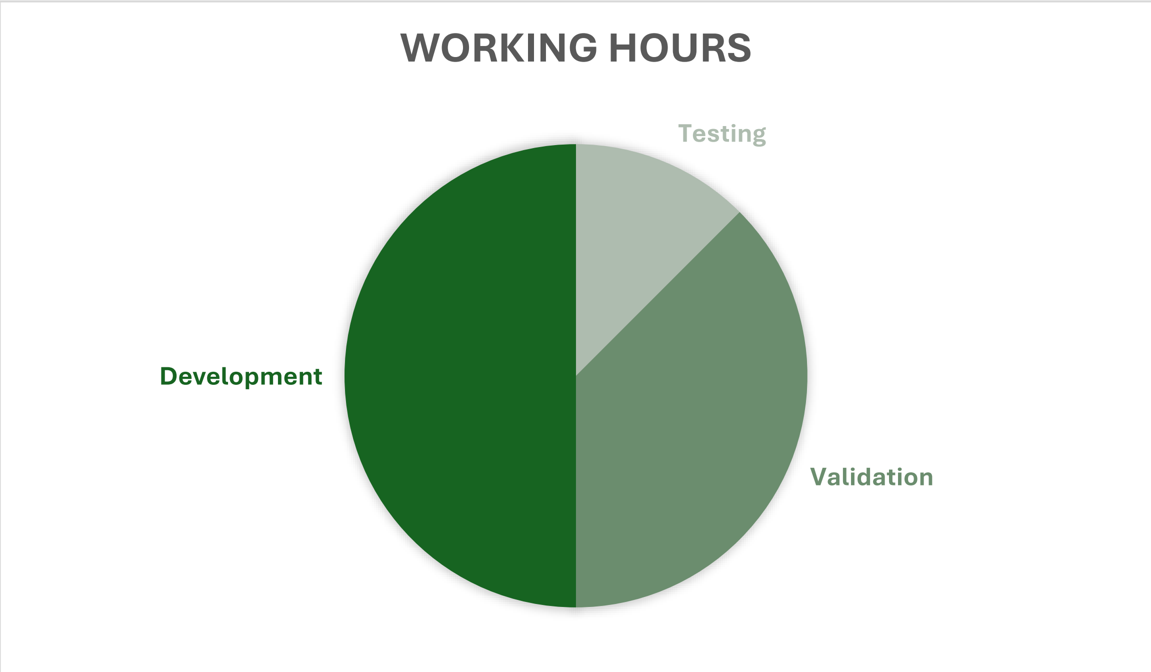
So, **the total cost of the vehicle**, including the entire system and car parts, **is $26,637.72.**

Cost of working hours

The total cost of working hours is calculated based on the type of work and the cost per hour for each category.

process	Number of hours	Cost per hour (USD)	Total cost
Development	4000	75	300,000
Validation	3000	85	255,000
Testing	1000	100	100,000

Total cost of working hours: 655,000 USD



Conclusion

The Autonomous Track Cost report offers a detailed and thorough financial analysis of the expenses involved in developing a fully autonomous system for electric vehicles. This comprehensive examination spans the selection and integration of sensors, mechanical fixation, validation processes, safety measures, and the cost of working hours.

The analysis of sensor and material selection highlights the importance of choosing high-quality components, such as LiDAR, cliff sensors, bumper sensors, wheel encoders, and IMUs, which are crucial for the system's overall functionality and reliability. The mechanical fixation section underscores the necessity of precise manufacturing and design processes to ensure secure sensor placement.

Validation is a critical step in the development of autonomous systems, and this report emphasizes the need for a well-justified validation approach, whether through simulation or real-world testing. The safety measures section demonstrates the importance of implementing robust software systems and communication protocols, such as OSEK, V2V communication, and sensor fusion technologies, to ensure passenger and vehicle safety.

Finally, the detailed analysis of working hours provides a clear view of the labor costs associated with software development, validation, and testing, offering insights into the human resources required for such a complex project.

By providing a comprehensive cost breakdown, this report serves as a valuable resource for stakeholders, enabling informed decision-making and strategic planning. It highlights the importance of balancing technological advancements with cost-efficiency to develop safe, reliable, and economically viable autonomous vehicles. The findings and recommendations presented in this report aim to support the ongoing innovation in autonomous driving technology, ensuring that it remains both cutting-edge and financially sustainable.