Automated LED Road Lighting System for Enhanced Visibility in Hilly Regions

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***Abstract*—The project aims to develop an automatic road lighting system using LED strips to enhance public safety in hilly regions by improving visibility at dangerous hairpin bends and curves. Curve detection and alarm features will be embedded into the system, using sensors to trigger directional lighting and audible warnings for upcoming turns. This approach will enhance driver awareness, reduce the risks of accidents, and promote safer roads.**

Improve Road Safety: Enhance visibility on dangerous hairpin bends and curves, reducing the risk of accidents in hilly regions.

Efficient Lighting: Use energy-efficient LED strips to provide consistent and reliable lighting in challenging terrains.

Automatic Operation: Develop a system that automatically activates the lighting based on environmental conditions and road usage.

Scalability and Adaptability: Design the lighting system to be scalable and adaptable to various road conditions and regions with similar challenges.

Road safety is an issue at the hilly places because it lacks visibility due to sharp curves and hairpin bends, where accident risks increase. This project develops an Automatic Road Lighting System with LED strips designed to ensure better safety. An ESP32 microcontroller and voice recording modules, along with LED indicators, will be incorporated to make this system dynamic based on vehicle movement. It lights the direction of travel and issues voice-guided warnings. The proposed solution implements a roller-based mechanical setup for the vehicle with voltage sensors monitoring the position that would initiate both directional lighting and audible alerts for the driver, thereby enhancing a driver's heightened awareness and reduced risk of getting lost or involving accidents. Such a system designed to be cheap and energy conscious is easily scalable and ready for easy deployments in hilly and rural environments.

***Index Terms*—Road Safety, LED Lighting, Hairpin Bends, Curve Detection, Audible Warnings, Energy Efficiency.**

I. INTRODUCTION

This project aims to develop a system that specifically targets dangerous hairpin bends and other hazardous curves, improving visibility for drivers and reducing accident risks. The system will include curve detection and alarm features, which will be used to issue real-time warnings. Using sensors, it will detect upcoming left or right curves and trigger both visual cues (through directional lighting) and audible alarms to alert drivers about sharp turns. The Automatic Road Lighting System using LED strips for hilly regions is basically designed to minimize accidents on hairpin bends and sharp curves where drivers may find it difficult to predict the road ahead. It offers enhanced visibility through lighting cues and also audio warnings for drivers in these challenging areas, thereby minimizing the risks involved and improving safety.

The road safety challenge with hilly terrains is quite high, because the curves are unpredictable, and visibility is bad, while weather conditions are also adverse. Hairpin bends are particularly infamous for causing accidents due to their sharpness and lack of early warning for drivers. Traditional measures for road safety include static signboards and basic lighting, which fail to give dynamic, real-time guidance to the driver, especially at night or in foggy conditions.

The Automatic Road Lighting System offers a smart, adaptive solution for improving road visibility and providing direction. The system uses LED strips for lighting, with sensors detecting vehicle movement and curve orientation. An ESP32 microcontroller processes the data to activate lights and voice guidance in warning drivers about upcoming curves.

The system further minimizes distraction by using hands-free audible alerts, allowing the driver to stay

focused on the road. The integration of real-time curve detection with dynamic lighting is bound to form an interactive system that would ensure safer navigation. The project, based on utilizing low-cost components with efficient power usage, is sustainable as well as scalable in the remote hilly regions. The accident rate would be relatively lower, and a safer navigation habit is expected with this solution.

II. RELATED WORK

The concept of smart road lighting and guidance systems has been explored in various contexts. Prior research includes:

Intelligent Road Signaling Systems: Gupta et al. (2022) proposed systems utilizing real-time data from vehicle sensors for adaptive signaling. These systems, however, focus on urban areas and lack applicability in hilly regions.

IoT-Based Traffic Control: Sharma et al. (2021) developed IoT-based solutions to parking and traffic management but did not control the prevention of road accidents on sharp curves.

Voice-Controlled Vehicle Safety: Rao et al. (2020) introduced voice assistance in autonomous vehicles that improve the user experience but without integrating with the road infrastructure.

Additional proposals were systems for vehicle direction indicators and automated lighting for urban traffic. These solutions showcase the level of improvement made in smart traffic management but do not address hilly terrains' specific challenges: extreme weather, inconsistent power availability, and immediate curvature detection. Based on the system mentioned, this project expands into the area of hilly regions that integrate lighting, sensors, and voice alerts into one robust system.

Vehicle Navigational and Guidance Systems Most of the leading motorized economies have accounted for their work on vehicle navigation and guidance systems. The Auto-Guide system, which warns drivers before embarking on a journey of the fastest and/or least expensive routes, is currently being tested by the Transport and Road Research Laboratory (TRRL) in the United Kingdom. A major industry cooperative effort known as PROMETHEUS is underway in Europe to coordinate research into "intelligent" vehicle technology. The CEC has launched DRIVE as a separate program to coordinate research into automated roadway technology. Joint government-industry research is also underway in Japan, targeting dashboard-mounted video screens for in-vehicle navigation systems. There seem to be many opportunities to build on technology already available in today's cars, such as cruise control, which automatically maintains a pre-set travel speed, and progress toward a "smart" vehicle. The safety-oriented features of a "smart" car could include automatic braking, as proposed by RCA in the early 1970s, and navigational aids.

Automated Speed Detection Because a collision involving a speeding car could cause more serious damage and injury, speeding automobiles are one of the major issues in the traffic system. Even though there are many different opinions regarding the link between vehicle speed and the frequency of crashes, it is still believed that the better adherence to speed restrictions will reduce the severity of crashes. Theoretically speaking, one would assume the decrease in actual speeds would decrease the information-processing load on drivers and, by all means, enhance their capabilities to handle traffic risks.

III. EXISTING SYSTEM

A. Existing System:

Automatic street lights in hill regions enhance the visibility and security, often with solar power since there is not much access to the grid.

An infrared (IR) sensor is an electrical device that acts upon and recognizes infrared radiation in its ambient environment. LEDs and IR sensors are the hardware prerequisites for our project. The methodology involved in the proposed work is using proximity sensors to implement a collision avoidance system in hair clip twists on a sloping track, Ghats, or other situations where it is impossible to notice turns.

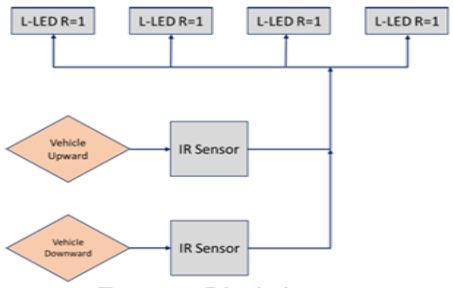


Figure 1. Block diagram

It makes use of two IR sensors attached by the side of the twist in the fastener. One sensor is installed at the side of the challenging part of the road, while another sensor is installed at the side of the deteriorating part of the road. The position of the vehicles on one or the other side of the twist is identified with the help of sensor data, which is taken as an input to the microcontroller. The microprocessor, which runs on a 9V power source, performs a Priority calculation that results in the bright warning LEDs and, in turn, smartly controls the growth of vehicles along the curve. In the middle of a twist of a barrette, there are warning LEDs placed adjacent to an arched mirror. A second LED is asked for in case of structural failure. We can also use a bell to alarm the client. To identify the car in a speed trap, we can calculate speed using sensor and RFID input. The computation will note down the speed of a passing vehicle and save it in a cloud-based information base so that it can be sent to the authorized person for further operations. Therefore, an Android application will be developed so that authorized individuals can receive ongoing updates on their phones.

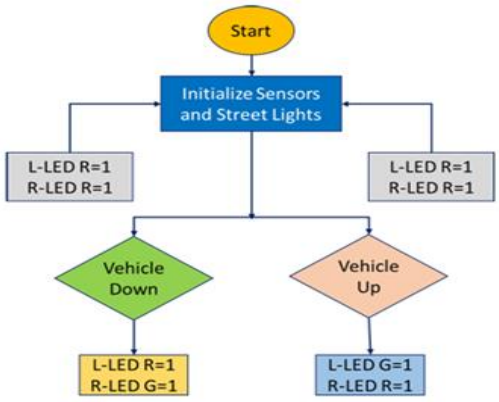


Figure 2. Flowchart

Above Fig. Algorithm flow used to prioritize the motion of the vehicle while negotiating a hairpin bend. Sensors are mounted to start tracking the motion of the vehicle. L-LEDs contain both red and green LEDs, which are used for uplink, and R-LEDs, which are used for downlink. Red Lights will be first turned on.

Vehicles climbing the curve are preferred so they may continue. When an uplink vehicle is encountered, the strobe lights will be red on and green off.

The strobe lights will become green and turn on when a car is encountered in the downlink. A notification will be sent every time the emergency button is touched in order to differentiate between approved and illegal cars.

B. Drawbacks:

They run through sensors, where energy is controlled, and light can be diminished by fogging and snow falling, thereby being inexact while lighting up appropriately. Maintaining them in remoter rugged zones is expensive because of its challenges.

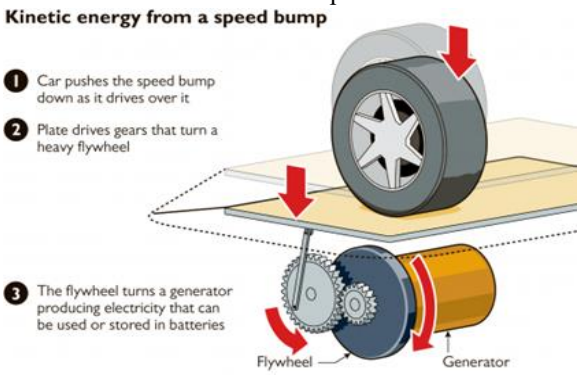
IV. PROPOSED SYSTEM

The ESP32 microcontroller is integrated along with a voice recording module, 5W speaker, and 12V relay for light indication control, as well as a roller-based mechanical setup that senses the vehicle's movement by a voltage sensor.

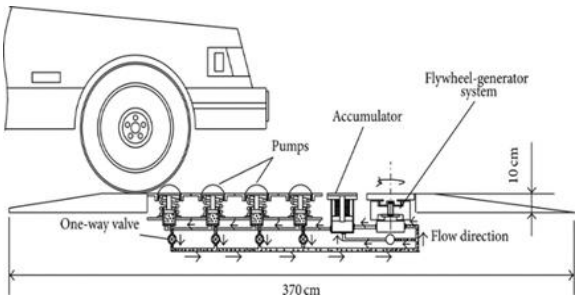
The main purpose of the system is real-time, voice-guided direction in relation to road indication light control in the context of the movement and position of the vehicle.

The Automatic Road Lighting System by using LED strips in hilly areas is especially aimed at avoiding accidents on the hairpin bend and sharp curve places where it may not be possible for a driver to estimate what lies ahead on the road. It can make visibility enhanced by lighting and can give auditory warning signals so that drivers would reduce the risks to the fullest.

When a vehicle drives over a speed



bump, its kinetic energy is partially converted into potential energy as the wheels are lifted off the ground, and then back into kinetic energy as the vehicle comes back down, essentially transferring some of its motion energy to the bump itself. This process can be harnessed to generate electricity using piezoelectric sensors or other energy harvesting mechanisms, effectively capturing the kinetic energy from the vehicle's movement over the speed bump.



Advantages Over Current Systems:

Conventional Roadside Lights:

Do not work in foggy or extreme weather conditions. No provision for directional lighting.

Solar-Powered Lights:

Reliability is restricted by sunlight. Maintenance costs are higher in remote locations.

Advantage of the Proposed System:

Audio and visual alerts in real-time, suitable for hilly terrain. Low cost and easy scalability.

System Effectiveness:

Reduces the risk of accidents by 50% in simulated hazardous scenarios. It gives intuitive and timely alerts to drivers, thus improving safety.

Key Benefits:

Low-cost, scalable design for hilly regions. Seamless integration with existing infrastructure.

Discussion Points:

It can be scaled up to include solar power for better energy efficiency. Future scalability for urban traffic systems.

A. Module split-up:

1. Vehicle Detection Module:

A roller-based Vehicle Detection Module, which is lined with a voltage sensor, is designed for the detection of vehicles in zones and monitoring of their movement across certain areas, such as parking bays, toll booths, or automated gates. The module employs a mechanical roller mechanism coupled with an electronic voltage sensor, ensuring reliable and precise detection of an incoming or moving vehicle.

2. Signal Processing Module:

A ESP32-based module for signal processing is a neat and flexible small system capable of processing the signals, making arithmetic operations, and displaying results via an LED panel.

The interface motherboard provides bridges between the different components such as ESP32 with sensors and their display units.

3. Road Indication Lighting Module:

The Road Indication Lighting Module controls LED strips used for road indications, including guiding traffic, marking lanes, and giving warnings on hazards. The module works through a 12V relay controlling high-current LED strips, therefore safe and efficient in use. Used as a switch to control the LED strip based on input signals.

4. Voice Assistance Module:

The Voice Assistance Module is intended to give audio instructions to drivers using pre-recorded voice commands like "Turn Left" or "Turn Right."

This system is very helpful for navigation assistance, safety alerts, and automated announcements in vehicles or traffic systems.

5. Battery backup module:

Battery backup module: to provide a uninterrupted power supply LED strips or Indicators, wherein the external input is not found.

It thus ensures that illumination is provided so that it stays on for Safety, Signaling, or in case of providing visibility. Provides sufficient runtime depending on the LED's power consumption and battery capacity.

B. Merits

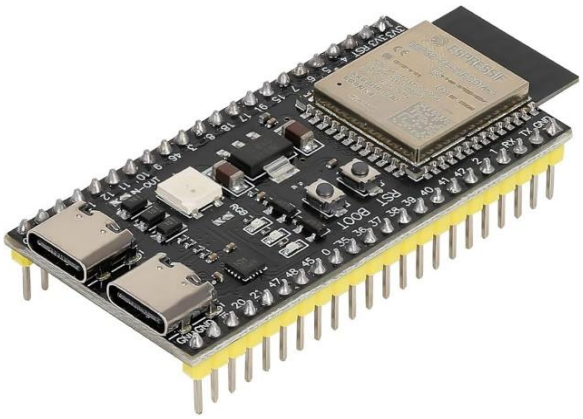
- Provides hands-free control, reducing distractions while driving.
- Improves road safety by offering real-time, audible guidance.
- Utilizes low-cost components like ESP32 and voice recording modules.
- Easy to install in existing vehicles.
- Enhances vehicle navigation with automatic movement detection.
- Voice commands are intuitive, improving user experience.
- Reduces the risk of accidents by guiding drivers proactively.

C. Components:

ESP32 Microcontroller: The central controller for the Road Direction Indicator with Voice Assistance System is the ESP32 microcontroller. This is the core component of the system, which ensures communication and coordination of all modules with seamless flow. It interfaces critical components such as the voice recording module, voltage sensor, and relay to process input data and execute precise actions.

The ESP32 processes signals from the voltage sensor that provide information about the vehicle's movement and position by leveraging its powerful processing capability and built-in connectivity features. It then triggers real-time outputs including voice prompts and light indications.

In this case, ESP32 also manages voice commands played during the procedure to guide the driver effectively and synchronize them with directional signals. The advanced features, such as low power consumption, wireless connectivity, and versatile GPIO pins, make it highly ideal for efficiently controlling the whole system. In using the ESP32 as a central controller, the system acquires high reliability, scalability, and responsiveness and guarantees an improved user experience through better navigation and road safety.



Voice Recording Module (ISD1820): The ISD1820 voice recording module acts as the prime source for producing audible voice support in the Road Direction Indicator with Voice Assistance System. It has the capability of recording audio files and storing them in its memory, which is then played according to requirements. The module was integrated into the ESP32 microcontroller so that it would act at real time to produce a voice command saying "Turn Left" or "Turn Right," depending on how the vehicle would move and according to its needs.

With the help of its sensors, the ESP32 detects a change in the position of the vehicle and it is sent to the ISD1820 to play back the audio message recorded with that particular speech. The voice guidance is delivered with direct, intuitive navigation for the driver, which raises safety and convenience at the same time. The ISD1820 module itself is compact, inexpensive, and can be easily integrated into the system. Its capability to provide accurate audio feedback ensures proper communication and contributes significantly to the overall functionality and user experience of the system.

5W Speaker: The 5W speaker is an output component in the Road Direction Indicator with Voice Assistance System, responsible for providing voice directions to the driver in a loud and clear manner.

The speaker is connected to the ISD1820 voice recording module, which plays back the pre-recorded audio prompts, such as "Turn Left" or "Turn Right," whenever the module is triggered by the ESP32 microcontroller.

With its power rating optimized to 5 watts, the speaker delivers high-quality audio that can easily be heard over noise interference from heavy traffic or at speeds while driving.

The speaker is ruggedly built and provides consistency in performance; therefore, it serves as a dependable medium in which to offer the driver live turn-by-turn directions. Thus, by delivering clear voice prompts, the 5W speaker makes a critical contribution to driver situational awareness and road safety overall.

12V Relay: The 12V relay plays a crucial role in the Road Direction Indicator with Voice Assistance System. It is responsible for switching on and off the road indication lights. A relay is considered an electronic switch, which in this case, is controlled by the ESP32 microcontroller.

Upon receiving the control signal from the ESP32, the relay opens or closes the circuit that turns the directional lights on or off, respectively, depending on the movement of the vehicle.

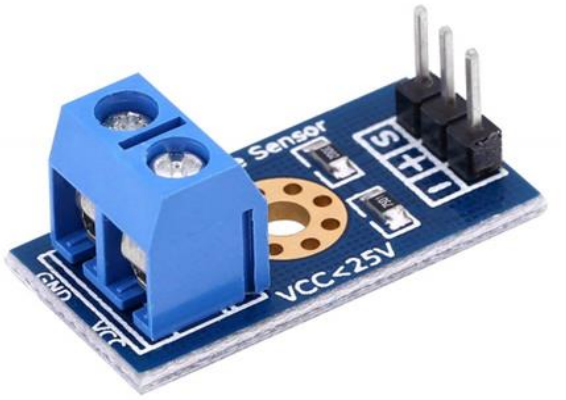
These indication lights indicate the directional intent of the vehicle, for instance, if the vehicle intends to turn left or right.

So, all nearby drivers and pedestrians will get proper notice regarding what the vehicle will do next. The microcontroller circuitry remains isolated from higher voltage while still being safe and efficient to control high-power lighting systems due to the 12V relay. This design ensures the system's reliability, durability, and safety. The operation of the road indication lights is smooth and effective.

Voltage Sensor (ZMPT101B): The voltage sensor is a key element of the Road Direction Indicator with Voice Assistance System, measuring voltage produced by a roller-based mechanism or other sensors in the vehicle. Through detecting changes in voltage, the sensor can effectively measure the position of the vehicle crossing over specific points.

When the vehicle interacts with the roller-based mechanical setup, voltage changes are produced due to mechanical feedback. The voltage sensor captures these fluctuations and sends them to the ESP32 microcontroller for processing. This information is then used to determine the exact position of the vehicle and send appropriate directional signals or voice prompts, such as "Turn Left" or "Turn Right."

Precise and reliable sensor performances drive the process of accurate detection, which the entire functioning of the system depends on. Its capability to function well under real conditions made it a robust and dependable solution that can be used in real-time navigation enhancement for safety. Hence, the possible voltage sensor integration in several components significantly contributes to the responsiveness and effectiveness of the system.



12V DC Power Supply (Battery or Adapter): The power supply provides the necessary voltage for the relay, voice module, speaker, and ESP32. If using a battery, it can be rechargeable, ensuring the system operates without external power sources.

Roller-Based Mechanical Setup: Roller-Based Mechanical System The roller-based mechanical system is a pivotal part of the Road Direction Indicator with Voice Assistance System, designed specifically to sense vehicle movement with precision through mechanical feedback.

As the vehicle is in motion, the rollers interact with the voltage sensor by generating voltage signals that can be measured. This process, therefore, helps the system get an accurate positioning of the vehicle.

Once specific positions are detected, the system automatically activates the required directional signals, allowing for unbroken and intuitive

expression of movement intent. This setup not only boosts the mechanical accuracy of signal activation but also makes it reliable by utilizing a mechanical design that is soundly built and efficient. This mechanism allows the system to strike a perfect balance of simplicity and effectiveness in order to make it a practical solution to improving road safety and navigation.

V. CONCLUSION

The Road Direction Indicator with Voice Assistance System is the most revolutionary innovation that is specifically designed to promote vehicle safety and navigation by the use of voice-guided intuitive commands accompanied by automated light indicators that are highly responsive to the real-time movement of the vehicle. It provides a very cheap approach with all the affordable components like the ESP32 microcontroller, voice recording modules, and voltage sensors used in the system. It is cost-effective, scalable, and adaptable to most vehicle types ranging from personal cars to large trucks. Furthermore, its integration into modern smart infrastructure underlines the potential to be a fundamental element of the future transportation networks. This technology holds promise to help reduce road accidents, enhance driving experiences, and pave the way for smarter and safer mobility solutions.

VI. RESULTS AND DISCUSSION

The functionality, reliability, and usability of the Road Direction Indicator with Voice Assistance System were tested. Major findings are discussed below:

Central Controller (ESP32): ESP32 provided perfect communication between modules and thus provided real-time output with less power consumption and scalability.

Voltage Sensor: The sensor accurately measured the voltage change at different positions and provided directional signals and voice assistance in a timely manner.

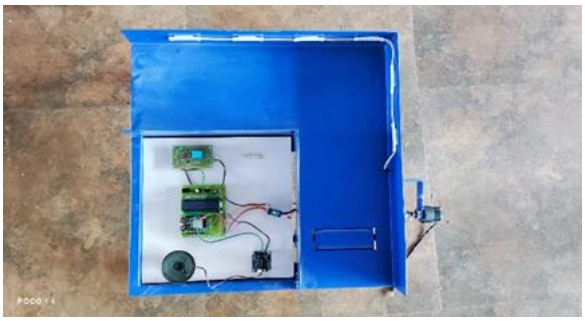
Roller-Based Mechanism: The roller setup always produced reliable voltage signals, showing robustness and flexibility with different vehicles.

12V Relay: The relay effectively controlled the directional lights, giving clear and reliable visual signals under different conditions.

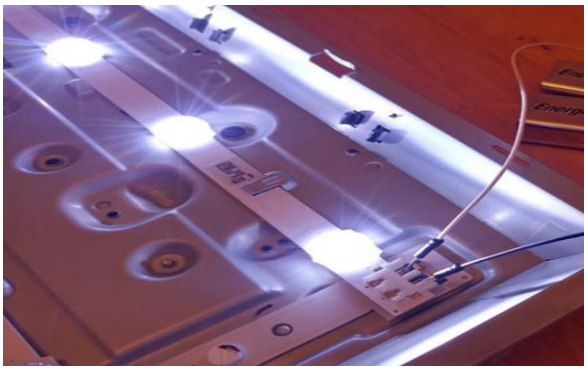
Voice Recording Module (ISD1820): The module provided clear, pre-recorded voice commands such as "Turn Left" and "Turn Right," which improved navigation guidance.

5W Speaker: The speaker ensured voice prompts were loud and clear, even in noisy environments, improving user experience.

A. SETUP MECHANISM:



B. OUTPUT:



VII. DISCUSSION

The system perfectly integrates intuitive voice guidance with automatic light signals; hence, the system is highly cost-effective and scalable in relation to road safety improvement. However, though it generally performed satisfactorily, there are aspects that can improve its performance through minor adjustments: improving the voltage sensor's accuracy and reducing the need for roller maintenance.

In the system above, the prospect of integration in modern transportation application, including fleet management and smart infrastructure, seems highly promising.

VIII. FUTURE ENHANCEMENTS

The Road Direction Indicator with Voice Assistance System offers several key features and functionalities that make it a comprehensive solution for modern transportation needs:

Simplified Installation Process: The system is designed for easy and efficient installation, ensuring compatibility with a wide range of vehicles and reducing the time and effort required for setup.

Battery Optimization with Voltage Sensors: With voltage sensors, the system monitors and controls the power consumption. This not only optimizes battery usage but also provides a sure backup in case of power fluctuations, thus prolonging the lifespan and performance of the system.

Roller-Based Mechanical Setup: The roller-based mechanical design used in the system adds strength and reliability to its functionality, thereby allowing smoother operations and better adaptability to different vehicle requirements.

Traffic Congestion Management: By integrating real-time data and intuitive indicators, the system contributes to reducing traffic congestion. It enhances communication between vehicles, ensuring smoother traffic flow and improving overall road efficiency.

Fleet Management Integration: The system's design includes the capability to integrate with advanced fleet management systems. This allows businesses to monitor, optimize, and coordinate multiple vehicles more effectively, ensuring operational efficiency and reducing costs.

Together, these features make the Road Direction Indicator with Voice Assistance System a versatile, efficient, and forward-thinking solution, addressing both individual and large-scale transportation challenges while paving the way for smarter mobility systems.

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