IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 1, August 2025
Impact Factor: 7.67

High-Tech Highway

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Abstract: *This paper suggests a technology-driven, integrated corridor for India's highways that combines four complementary innovations: fully automated mobile toilet reverse osmosis (RO) water-purification stations solar-powered artificial trees for air-quality management and sustainable road-construction strategy that re-engineers pavement materials, sub-grade soil, and median design. In order to provide hygienic sanitation while lowering open defecation and water consumption, the mobile toilets use touchless RFID/QR access, UV-C self-cleaning, IoT-based waste-level sensing, bio-digester treatment, and solar energy. Under continuous sensor-based quality monitoring, highway-side RO plants provide passengers with mineral-balanced potable water, support smart rest-stop cleaning operations, and provide emergency supplies during natural disasters. Artificial trees made from recycled metal with photovoltaic "leaves" provide bird nesting opportunities, produce renewable electricity, and extract greenhouse gases up to 1,000 times faster than natural vegetation.*

Keywords: Mobile toilet, Highway, Recycling

I. INTRODUCTION

1.1 Mobile Toilets:

The suggested mobile toilet module installs a stainless steel/FRP superstructure on a trailer chassis and incorporates smart features such as sensor-driven vacuum flush, UV-sterilizing self-clean, RFID/QR touchless entry, HEPA-carbon odour control, and a cloud dashboard that sends out predictive maintenance alerts. Wheelchair ramps, Braille panels, and SOS alarms guarantee universal accessibility, and solar PV panels and a biodigester make the unit waste-neutral and energy-positive.

1.2 Highway Construction:

Recycling landfill-bound waste by dry-process blending 3–7% shredded plastic or biodegradable waste with bitumen increases Marshall stability by up to 9% for Stabilizing the soil with 20% fly ash activated by 10 M NaOH increases unconfined compressive strength by 30% to 40% while reducing the incidence of potholes and embodied CO_2. These are narrow, vegetation-lined channels that serve as ecological corridors and raise groundwater levels by 6–8% by collecting 12–15,000–15,000 L of monsoon runoff per 500 m stretch. Figure.1. explains the composition present in highway construction.

1.3 RO plant:

At rest areas, RO plants draw water from municipal or bore-well sources and filter it through a series of pre-filters and reverse osmosis membranes that are monitored by TDS sensors. The installations maintain a disaster-ready reserve, provide mineral-free rinse water for solar panels and EV charging hardware, and dispense safe drinking water. PV arrays reduce operating costs, and IoT telemetry integration allows automated cartridge-change alerts.

1.4 Artificial Trees

Artificial trees replicate photosynthesis on an industrial scale where traditional planting is not feasible. An algae inspired catalyst transforms CO_2 into O_2, while fans draw polluted air through HEPA and activated carbon layers.

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Lithium-ion batteries that power Wi-Fi hotspots, USB-C charging ports, and LED safety lighting are fed by flexible monocrystalline PV "leaves," with excess energy being directed to adjacent restrooms or RO units. Bird nests and rain- and lightning-proof frames are also part of the design.

1.5 Motivation

Alongside these issues are sanitation gaps, potable water scarcity, urban air pollution, pavement deterioration, and rain-water waste on India's 70000 km national highway network. These multifaceted demands cannot be met by traditional, single-purpose infrastructure; therefore, an integrated, technology-enabled approach is crucial.

1.6 Structure of the Paper:

This paper's remaining sections describe component architectures, cost-benefit analyses, prototype testing, and deployment strategies, and it concludes with a systems-level assessment of how these four innovations work together to future-proof India's highways against socio-environmental stresses.

1. Highway:

The conventional form of highway is also transforming with the adoption advanced technologies resulting in improved safety, efficiency and environmental impacts

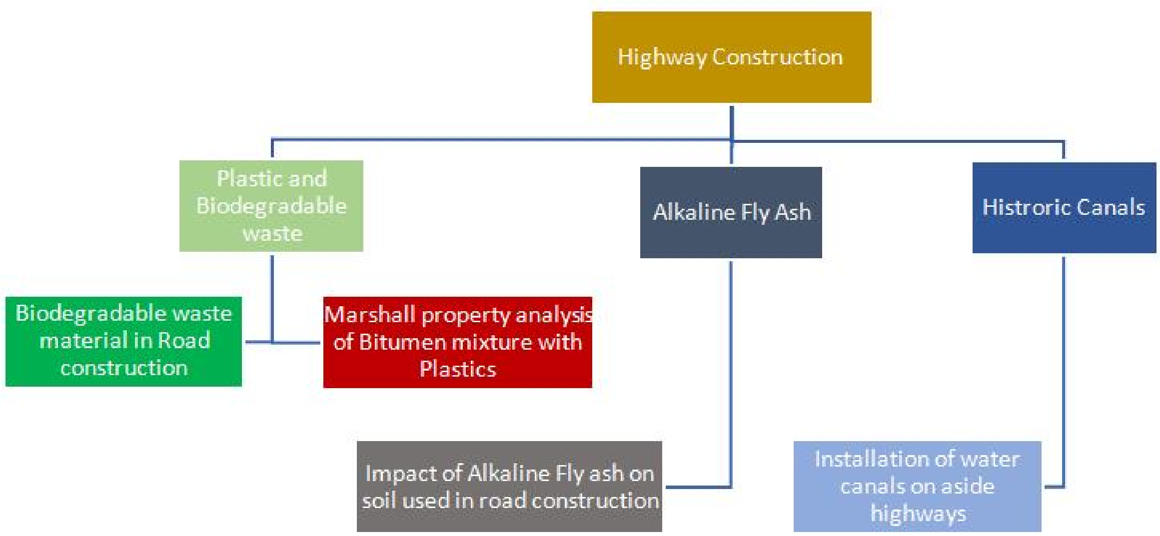

Figure 1. Highway construction

Materials and Design New research has examined the potential of self-healing concrete, plastic roads, and waste materials to minimize the impact on the environment. Sensor Integration: Sensors for Internet of Things (IoT) integrated into high ways to monitoring traffic flow, and load, maintenance process is a growing area.

2. Mobile Toilets Highways:

Mobile sanitation facilities are essential for hygiene and health on extensive road networks, as exists in remote/overloaded regions. Technological Breakthroughs: Incorporation of bio-digester toilets, vacuum flush systems, solar light generation from waste inside the latrines. Intelligent Monitoring for Embedding the real-time waste level monitoring and the cleanliness status update using IoT has been planned for the ease of maintenance. Reports address Ideal placement through GIS Data that is capable of increasing reach and decreasing costs.

DOI: 10.48175/IJARSCT-28660

3. RO (Reverse Osmosis) Plant Highways:
Ensuring drinking water at highway rest stops is important, particularly in hot climates or in under-developed regions. Small RO Plants is implemented at rest areas which include mobile, solar powered RO plants are being set up. Sustainability Investigate water recycle, energy recovery and membrane longevity.
Intelligent Monitoring for Digital sensors to monitor TDS, water quality and maintenance scheduling.

4. Artificial Trees Highway:
Engineered structures known as artificial trees replicate the environmental roles of natural trees, including Carbon capture storage.Air purification with activated carbon filters or moss (e.g. Germany).
Energy production using piezoelectric materials or integrated solar panels.Can be combined with Wi-fi hubs or EV charging station for multifunctional use.

II. PROTOTYPE

1. Automated Mobile Toilet
To realize the concept of the fully automated mobile toilet, the first prototype will be built in the form of a small, trailer-based unit for mobility and deployment in highway rest stops. The design will use durable yet lightweight materials like stainless steel or fiberglass-reinforced plastic, which will be easy to tow but durable in various climatic conditions.
Inside, the prototype will demonstrate the functionality of touchless entry through RFID or QR code scanners at the door. The solitary toilet cubicle will have self-cleaning amenities - such as water jet nozzle, UV-C disinfection, and antimicrobial seats that self-sterilize on each use. Motion sensors integrated taps, soap dispensers, and hand dryers will give passengers an entirely touchless experience.
For smart monitoring, there will be IoT sensors onboard to track the waste tank level, air quality, water usage, and occupancy. Everything will be displayed on a user-friendly cloud-based interface to allow remote tracking. Solar panels will be placed on top of the roof to confirm the capability of the unit to sustain itself from renewable energy sources. There will be a small bio-digester tank that will treat waste internally, closing the loop for sustainability. This small pilot unit will be piloted at a busy location to gain actual user feedback
and maintenance data before installing multiple units along highways.

2. Sustainable Highway Construction
The sustainable highway construction prototype will be created as a short test segment of road - approximately 100 to 200 meters in length - ideally off a current highway. This section will illustrate the way shredded plastic trash can be incorporated in bitumen to make a more resistant, longer-lasting asphalt mixture. The paving equipment will be utilized in the same way as in traditional road construction, and thus the process remains feasible for massive construction.
Beneath the asphalt pavement, the soil will beensors of sodium hydroxide will be stabilized by a fresh geopolymer mix of fly ash. This will be done to strengthen weak subgrade soil, reducing pothole and crack occurrence in the future. CBR (California Bearing Ratio) and unconfined compressive strength tests are to be carried out in order to measure improvements.
In the median of the highway, a small canal system with indigenous plants will be installed to demonstrate how rainwater can be collected, purified, and utilized for the recharging of groundwater. Infiltration rates and water retention during storms will be monitored by sensors. This living model will allow engineers to discover cost considerations, environmental impacts, and real-world problems before the solution is applied at larger levels.

3. RO Plant for Highways
The RO Plant model for highways will be a stand-alone, portable unit, no larger than can be accommodated on a concrete slab beside a toll booth or rest stop. It will have a number of pre-filters, a high-pressure reverse osmosis membrane, storage tanks, and an automatic dispensing system.

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Solar panels at the top of the unit will power the pumps and sensors so that there is always clean water available even in areas with uncertain power supply. People visiting will be able to see real-time TDS values on a small screen, allaying concerns about the cleanliness of the water being consumed.

The pilot will also experiment with touchless water kiosks or bottle-refilling stations to maintain hygiene. The plant will not only offer drinking water, but also mineral-free water for cleaning sensitive items like EV charging stations and solar panels. The intelligent RO Plant will be field-tested to monitor actual water demand, maintenance cycles, and to what extent it can serve travelers during emergencies like floods or power outages.

4. Artificial Tree for Highway

The artificial tree model would combine air purification, harvesting of clean energy, and city greenery in a functional single unit. The model tree will be put to test at a highway rest stop or traffic junction that is heavily manned by traffic.

It will be built with a sturdy base made of recyclable or sustainable metals covered by leaves that carry bendable solar panels in the form of leaves. The panels will generate electricity in the daytime and stock it in inbuilt batteries that will energize LED lights, charging stations for phones, and even Wi-Fi hotspots for travelers.

Inside the trunk, advanced filters will suck in polluted air and trap dust, carbon dioxide, and other toxic gases. Through a photo synthesizing-like process, cleaner air will be released into the environment. Birdhouses and seed feeders will be added to offer wildlife assistance in the vicinity, with this prototype giving a modest but substantial boost for biodiversity.

The tree will also include a lightning protection system for safety. The testing in the real world will help to quantify air quality improvement, energy generation efficiency, and public participation - all of which will inform how these trees can be scaled and adapted for use in other parts of a high-tech highway.

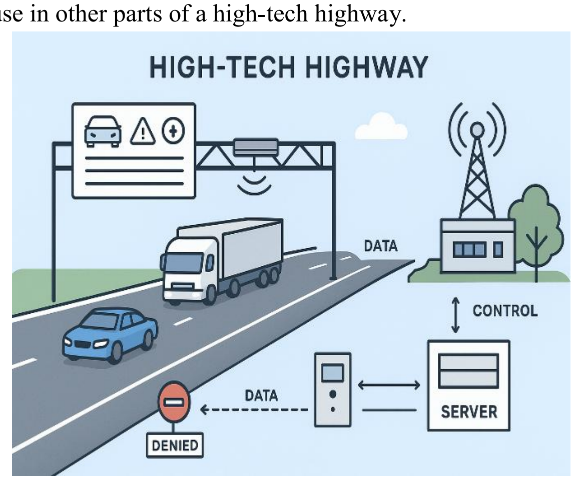

Figure 2. High-tech Highway general block diagram

III. DESCRIPTION OF INTELLIGENT TRANSPORT SYSTEM

3.1 TRAFFIC MANAGEMENT CENTRE

Role: This is the “brain” of the system.

Functions: Data Platform & Digital Twin: Collects massive amounts of live data from roadside sensors, connected vehicles, and external sources. Uses analytics, AI/ML to forecast traffic flow, detect incidents, and simulate “what-if” scenarios.

Control Applications: Generates control strategies adaptive signal timings, lane control, variable speed limits, ramp metering, dynamic toll pricing.

Traveler Info & APIs: Publishes real-time info to message boards, mobile apps, navigation systems, and public APIs.

3.2 BACKHAUL NETWORK

Role: The communication backbone between field devices and the TMC.
Tech Used: Fiber optic, LTE/5G, microwave, DSRC/C-V2X, and even satellite as backup.
Function: Ensures two-way high-speed, low-latency data and control transmission.

3.3 ROADSIDE & FIELD LAYER

Roadside Units (RSUs): Communicate directly with vehicles via V2X (Vehicle-to-Everything) standards like C-V2X or DSRC. They can send MAP/SPaT messages (map geometry, signal phase, and timing), hazard alerts, or toll prices.
Edge Computing (MEC): Local roadside servers process data right at the source for ultra-low latency control—useful for automated vehicles and instant safety alerts.
Field Actuators: Devices that physically implement TMC commands:Variable Message Signs (VMS/DMS), Lane control signals, Ramp meters, Automated barriers or beacons, **Field Sensors:** CCTV, ANPR (automatic number plate recognition), radar, LiDAR, inductive loops, weigh-in-motion scales, weather stations, noise/air quality monitors.
Connected Vehicles: Send "probe" data (speed, location, events) and receive instructions, alerts, or dynamic pricing.
Mobile Apps & 3rd-Party Services: Navigation, MaaS (Mobility-as-a-Service) payment systems, ride-sharing platforms—all feeding and consuming data.

3.4 EXTERNAL INTERFACES

Integration with: Police, fire, EMS dispatch (CAD/911), towing, work-zone management, utility companies, payment gateways, and security operation centers (SOC).

3.5 DATA FLOW

Upstream (Field → TMC): Sensors detect events, traffic speed, weather conditions. Vehicles send telemetry and crowdsourced incident reports. Tolling/enforcement send vehicle ID, speed, violations.
Processing (At TMC & Edge): Data is analyzed in real-time for congestion detection, accident alerts, travel time calculation.
Downstream (TMC → Field): Commands sent to roadside devices to change speed limits, open/close lanes, display messages, adjust toll rates. Traveler info updates sent to apps and signs.**V2X Broadcast:** Safety and navigation data sent directly to connected vehicles for driver assistance or autonomous navigation.

IV. RESULT AND CONCLUSION FOR HIGHWAY

1. Highway Construction

Results:

The general block diagram of High-tech highway is shown in figure.2. A high quality durable and smooth road surface can be achieved using modern materials as plastic waste.Smart features were integrated automated lighting solar powered signboard and vehicle detection sensor.Reduced travel time by up to 30-40% for commuters.Lower maintenance costs due to advanced drainage and weather resistant construction.

Conclusion:

The integration of advanced material and smart technology in highway construction enhance durability safety and traffic efficiency. It sets a new standard for future infrastructure development with minimal environment impact and high user satisfaction.

2. Mobile Toilets

Results:

Clean and accessible mobile toilet installed at regular intervals. Equipped and accessible mobile toilet installed at regular intervals. Usage monitoring through IOT sensors showered steady increase in public adoption especially among long distance passengers. Reduced open defecation and improved roadside sanitation. Reduced open defecation and improved roadside sanitation.

Conclusion:

Mobile smart toilets are a critical success factor for hygiene and public health on highway. Their deployment not only improve convenience but also significantly support government initiatives like Swachh Bharat Abhiyan

3. Artificial Trees

Results:

Artificial trees with air-Purifying capabilities were installed every 100 meters in polluted zones.Integrated were solar panel and sensor to monitor.Function as smart hubs providing Wi-fi and charging point for EV and mobile devices.

Conclusion:

Artificial trees serve as dual purpose and actively contribute to environment sustainability while enhancing the highway technological image. Their use in pollution heavy area is highly recommends Artificial trees serve a dual purpose—aesthetic and functional. They actively contribute to environmental sustainability while enhancing the highway's technological image. Their use in pollution-heavy areas is highly recommended.

4. RO Plant Installation

Results:

RO water purification units installed at rest area, toll plazas and service stations.

Each plant serves over 500-100 passengers per day providing clean and safe drinking water.

Wastewater from RO reused for gardening or toilet flushing.

Conclusion:

Access to clean drinking water is essential for highway users.RO plant enhance public health promotes sustainability and reduce plastic bottle waste. High feasibility for expansion on all national highway.

V. OVERALL CONCLUSION

The High-tech Highway initiative demonstrates how technology and infrastructure can combine to create smarter cleaner and safer travel environment with improved hygiene environmental monitoring clean water access and traffic efficiency this project can serve as model for future ready infrastructure in both urban and rural settings.

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DOI: 10.48175/IJARSCT-28660