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- **PROBLEM STATEMENT ID :** 1740
- **PROBLEM STATEMENT TITLE :** Development of Map-Matching algorithm using AI ML techniques to distinguish vehicular movement on highway and service road
- **THEME :** Smart Automation
- **PS CATEGORY** : Software
- **TEAM ID** : 29791
- **TEAM NAME** : Barely Made It

"In a world of imperfect data, true innovation lies in creating clarity from chaos."

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Adaptive AI-ML System for Accurate Vehicle Path Detection

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DEVELOP AN AI-ML BASED ALGORITHM THAT DISTINGUISHES BETWEEN VEHICLE MOVEMENT ON HIGHWAYS AND SERVICE ROADS, EVEN WITH INTERMITTENT OR BIASSED GNSS DATA.

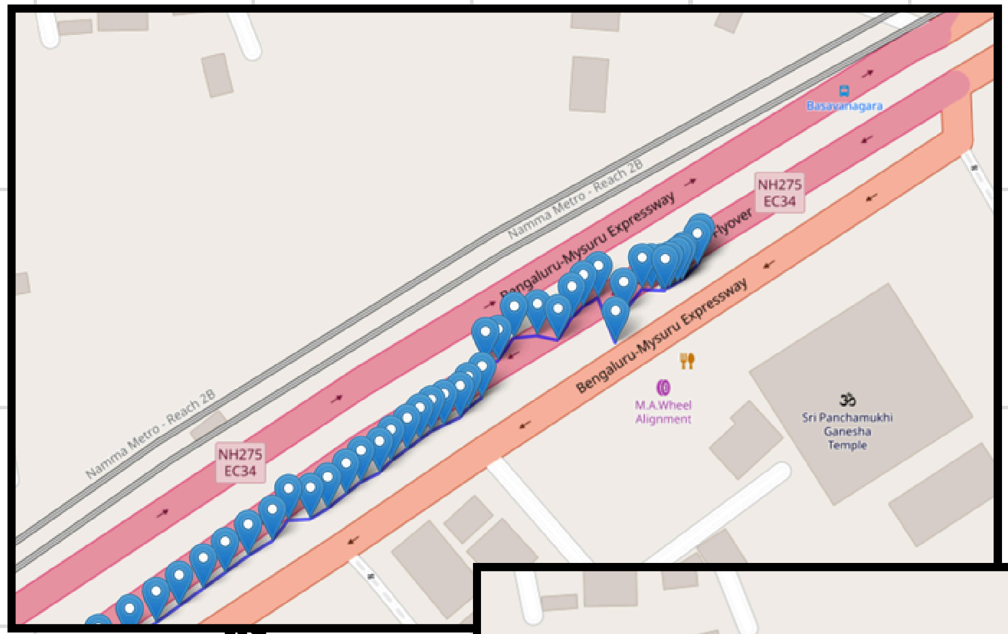
PROBLEM IDENTIFICATION

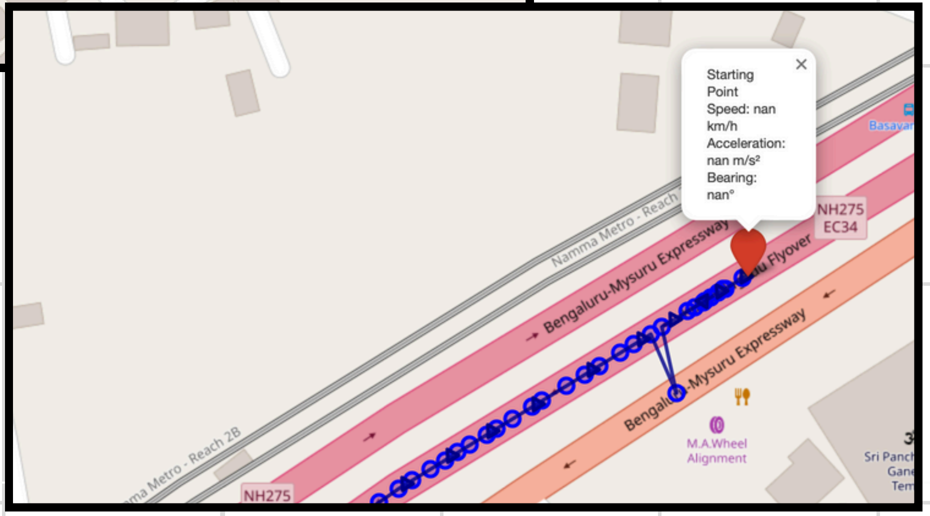
- **High Bias in Coordinates:** The GNSS data is coarse, leading to high bias in the positioning, especially in environments where multiple roads are closely spaced.

- **Increased Path Complexity:** Complex maneuvers like U-turns, road transitions, flyovers, and frequent highway entries/exits cause high trajectory variability, leading to GNSS misalignment with the actual path

- **Misalignment of Points**: As a result, data points can appear to be between roads, or sometimes in the middle of a road, even if the actual path taken is along a specific road (e.g., a highway versus a service road).

- **Trajectory Inaccuracy**: Frequent direction changes and road transitions (e.g., main road to ramp or flyover) worsen GNSS inaccuracies, causing real-time adjustment issues and erroneous path plotting, especially in areas with parallel roads or limited satellite visibility.





PROBLEM ADDRESSED

Development of a vehicle movement tracking system that utilizes coarse GNSS position data to plot the vehicle's trajectory on OpenStreetMap. Integrated OSRM for identifying the vehicle's path on highways or service roads, and applied Hidden Markov Model to enhance map-matching accuracy and performance.

INNOVATION & UNIQUENESS

Novelty

COMBINING AI/ML WITH MAP-MATCHING

ROBUSTNESS TO GNSS ISSUES

Scalability

DATA AVAILABLITY AND QUALITY

LOW INITIAL INVESTMENT COST FOR MODEL DEPLOYMENT

Viablity

TECHNICAL FEASIBILITY: OPENSTREETMA P

OPERATIONAL FEASIBILITY: INTEGRATION WITH EXISTING INFRASTRUCTURE:

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TECHNICAL APPROACH

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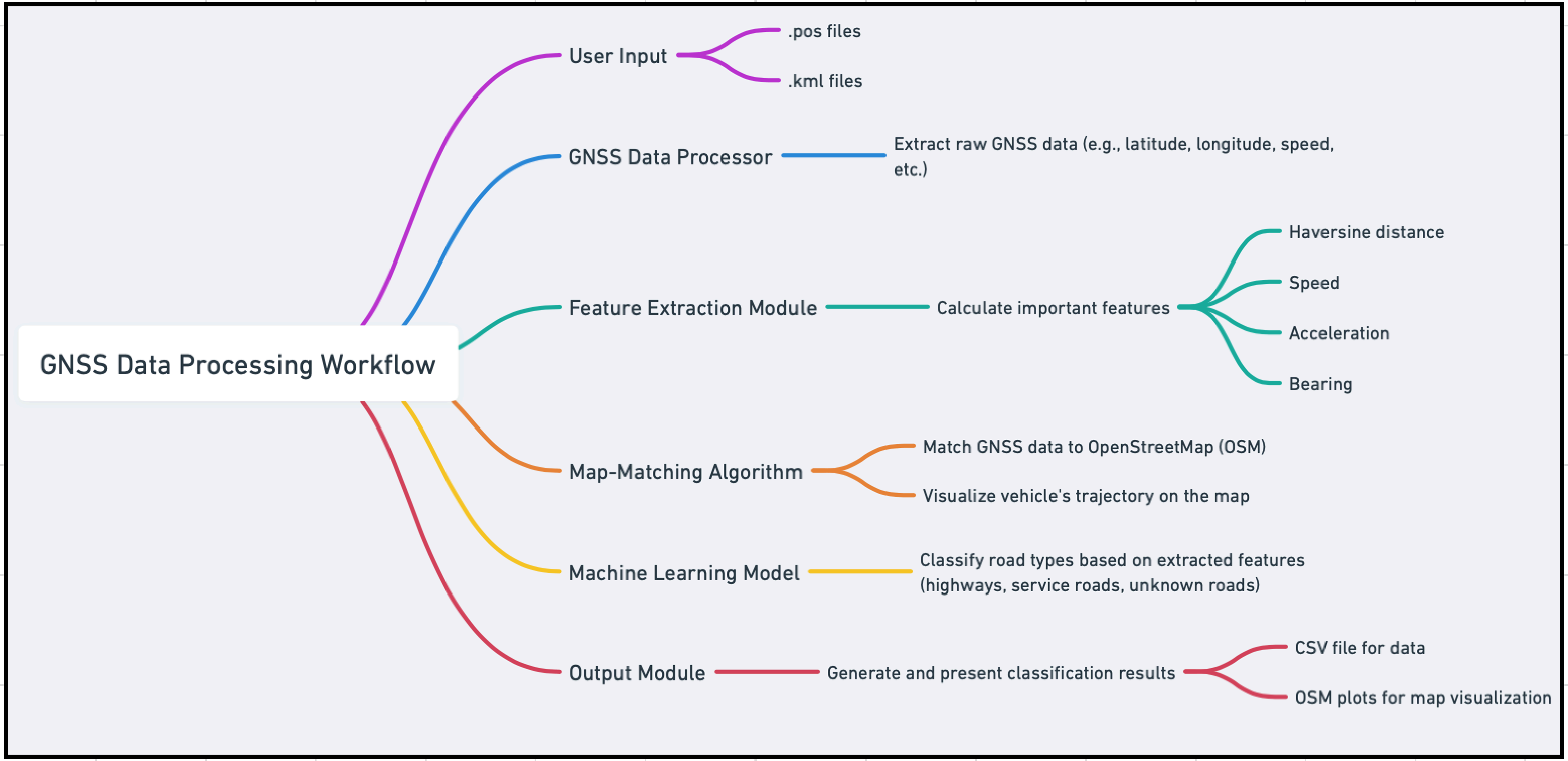
FRAMEWORK USED

OSRM
OPEN SOURCE ROUTING MACHINE
NumPy
OpenStreetMap
pandas
Folium
Flask
HTML
CSS
JS

PROCEDURE FLOW CHART



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THE WORKFLOW

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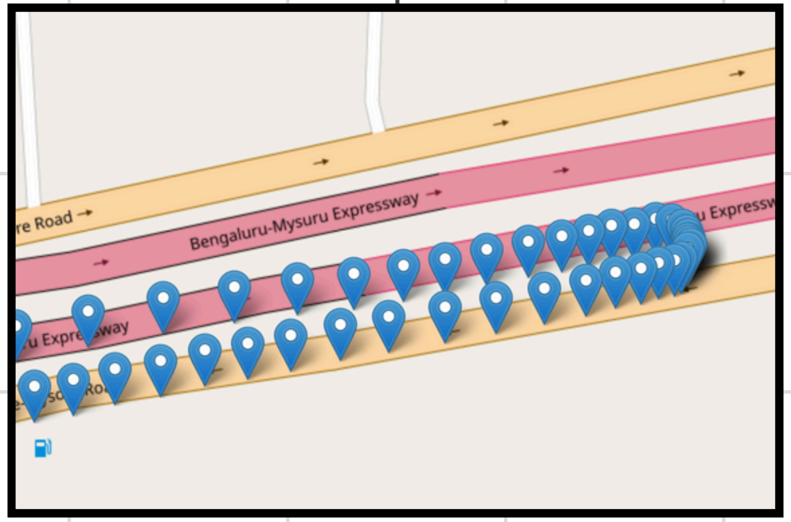
- GNSS DATA POINTS SHOW HIGH BIAS, WITH INACCURATE MAPPING AND NO CLEAR DETERMINISTIC TRAVEL PATH.

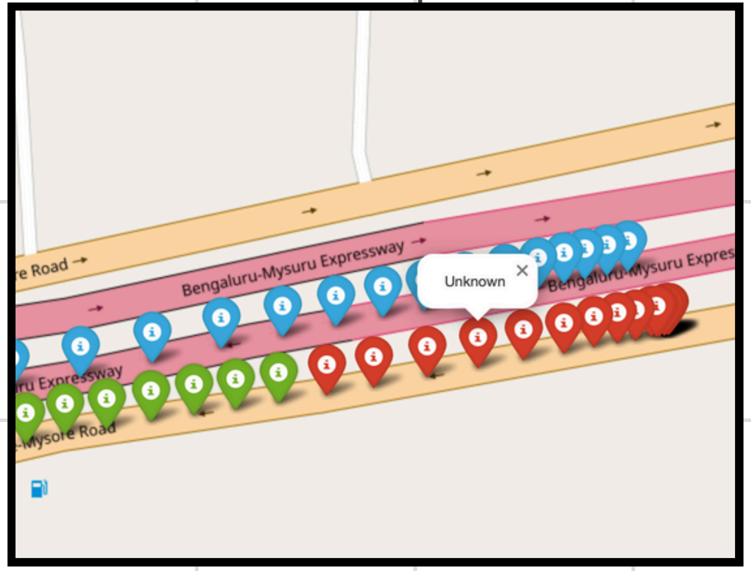


RAW GNSS DATA PLOT

UNIQUE ROAD NAMES & ROAD TYPES

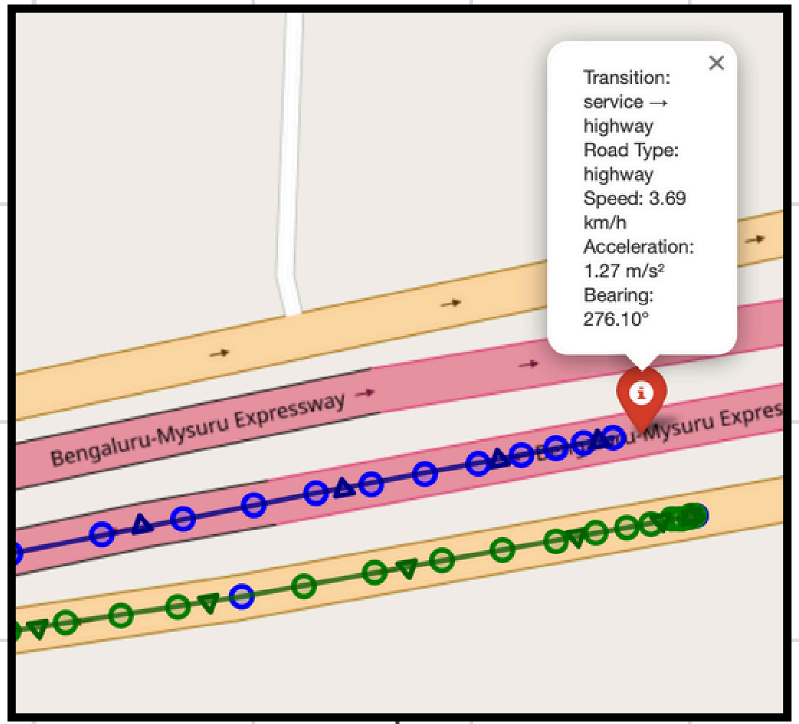
road_name	road_type
Bangalore-Mysore Road	service
Bengaluru-Mysuru Expressway	highway

- USING OSRM API , SNAPPING COORDINATES TO NEAREST ROAD
- CLASSIFICATION ON THE BASIS OF ROAD NAMES



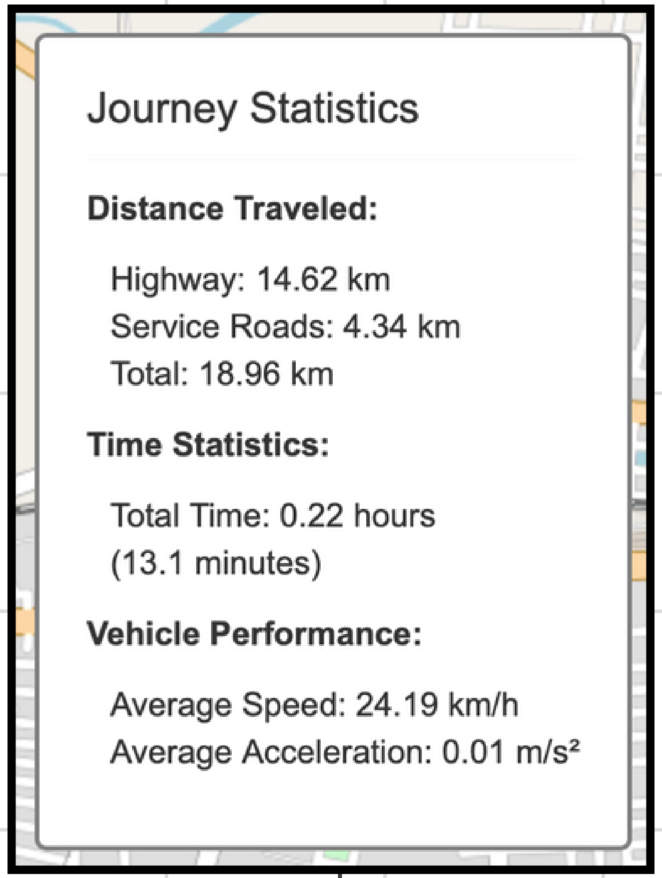
SNAPPED COORDINATES WITH ROAD TYPES

PREDICTION OF UNKNOWN POINTS USING HMM



- GENERATION OF ACCURATE PATH TAKEN ON HIGHWAY & SERVICE ROAD
- INDICATING TRANSITION & FEATURES RELATED TO EACH DATA POINT

JOURNEY STATISTICS



- CALCULATING THE OVERALL DISTANCE TRAVELLED INCLUDING DISTANCES ON HGHWAY & SERVICE ROAD
- INDICATING VEHICLE FEATURES LIKE SPEED , ACCELERATION & TRAVEL TIME

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FEASIBILITY AND VIABILITY

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CURRENT SOLUTION

NavIC (IRNSS): India's indigenous satellite navigation system provides enhanced positioning accuracy, especially within the Indian region.

Map-Matching Algorithms: Techniques that snap GNSS data points to the nearest road on a digital map, improving the interpretation of vehicle paths, especially in dense urban areas.

AI-ML Based Signal Correction: Machine learning models are used to detect and correct **non-line-of-sight (NLOS)** and **multipath errors**, improving GNSS accuracy in urban environments.

LIMITATIONS OF CURRENT SOLUTIONS

Infrastructure Compatibility: Widespread adoption of NavIC requires upgrades to existing GNSS receivers and vehicle navigation systems, which can be costly and logistically challenging.

Multi-path and Urban Canyon Effects: GNSS signals reflect off buildings in cities, creating positioning errors, which are still difficult to mitigate fully in real-time

Real-Time Processing Limitations: AI-ML models for GNSS correction require high computational power and network support, which poses challenges for instant error correction at scale.

FEASIBILITY OF OUR SOLUTIONS

Technical Feasibility

This approach can effectively mitigate issues caused by signal loss in urban environments, enhancing the reliability of vehicle location data.

Economic Feasibility

Utilizing existing vehicles for data collection minimizes additional costs associated with upgrading GNSS systems or infrastructure.

Operational Feasibility

By regularly updating models with fresh data, the solution can adapt to new driving patterns, environments, and GNSS signal variations over time

STRATEGIES TO OVERCOME CHALLENGES

Multi-Sensor Fusion: Mitigate signal loss with combined data sources.

Crowdsourcing Data: Average out variability using data from multiple vehicles.

Incremental Model Training: Continuously update models with new data.

AI-ML Based Signal Correction: Use CNNs or LSTMs to detect NLOS and multipath errors, trained on urban GNSS distortion.

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SWOT Analysis

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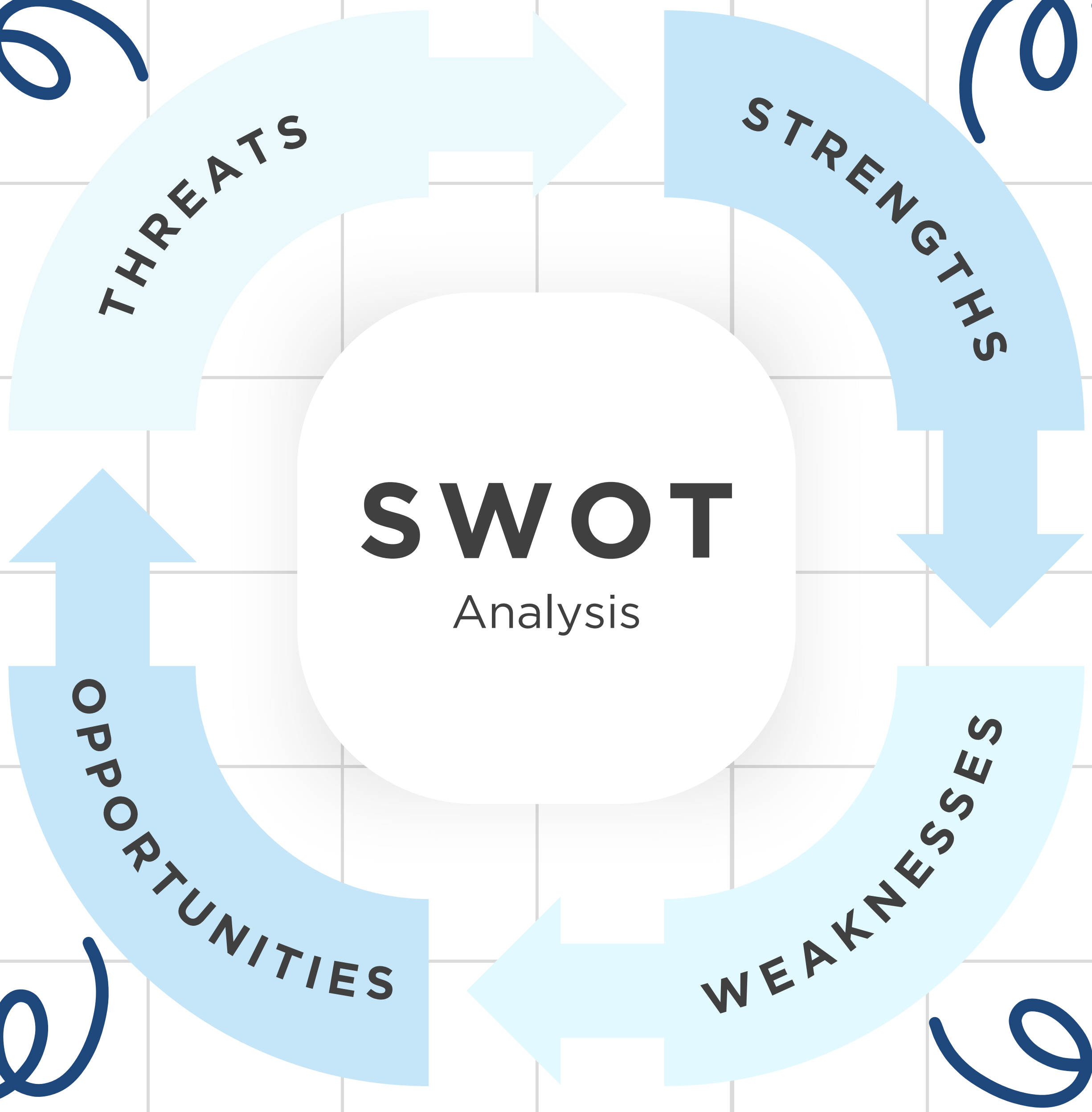
DATA PRIVACY:
COMPLIANCE WITH DATA PROTECTION LAWS (E.G., GDPR, CCPA) FOR LOCATION TRACKING DATA.

GNSS SIGNAL INTERFERENCE:
SIGNAL LOSS OR DEGRADATION IN AREAS LIKE TUNNELS, URBAN CANYONS, OR REMOTE REGIONS COULD LEAD TO INACCURATE CORRECTIONS.

GNSS BASED TOLLING
GNSS-BASED TOLLING OFFERS AN INNOVATIVE SOLUTION TO ADDRESS THE CHALLENGES POSED BY TRADITIONAL TOLL COLLECTION METHODS. AS A TECHNOLOGY-DRIVEN OPPORTUNITY, ALIGNING WELL WITH THE EVOLVING TRANSPORTATION LANDSCAPE.

LOGISTICS OPTIMIZATION:
THE MODEL COULD BE USED IN LOGISTICS TO OPTIMIZE FLEET ROUTING, REDUCING INEFFICIENCIES CAUSED BY POOR MAP DATA OR GNSS ERRORS.

INSURANCE INDUSTRY:
SUPPORT TELEMATICS-BASED INSURANCE BY ANALYZING DRIVING BEHAVIOR AND PROVIDING DATA FOR DYNAMIC PRICING MODELS.



CONTINUOUS LEARNING:
THE MODEL CAN BE UPDATED WITH NEW DATA TO IMPROVE ACCURACY OVER TIME, ENABLING IT TO ADAPT TO CHANGING ROAD CONDITIONS OR NEW GEOGRAPHIC REGIONS.

MULTIVARIATE FEATURE UTILIZATION:
INCORPORATES DIVERSE FEATURES LIKE SPEED, ACCELERATION, BEARING, AND HAVERSINE DISTANCE TO DISTINGUISH BETWEEN ROAD TYPES AND ACCURATELY MAP VEHICLE MOVEMENT

FEATURE-RICH ANALYSIS:
EXTRACTS KEY FEATURES LIKE SPEED, ACCELERATION, BEARING, AND DISTANCE TO IMPROVE ROAD CLASSIFICATION AND MAP-MATCHING.

HIGH LATENCY IN REAL-TIME SYSTEMS:
EXTERNAL API CALLS AND COMPLEX MODEL COMPUTATIONS MAY INTRODUCE LATENCY, AFFECTING THE MODEL'S PERFORMANCE IN TIME-SENSITIVE APPLICATIONS LIKE AUTONOMOUS DRIVING

INTEGRATION WITH AUTONOMOUS SYSTEMS:
POTENTIAL TO INTEGRATE WITH AUTONOMOUS VEHICLE NAVIGATION SYSTEMS FOR ENHANCED MAP-MATCHING AND TRAJECTORY CORRECTION IN DYNAMIC ROAD ENVIRONMENTS.

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Financials

USER PERSONA

- **Efficiency and Cost Management:** The government aims to reduce infrastructure costs by eliminating toll booths, ensuring more efficient toll collection, and lowering operational expenses through automated, distance-based GNSS systems.
- **Data-Driven Policy Making:** The government seeks access to real-time data on traffic patterns and vehicle movements, enabling better road planning, congestion management, and the implementation of dynamic pricing strategies.

- **Convenience and Time Savings:** Citizens benefit from seamless, contactless tolling without stopping at booths, leading to faster commutes, reduced wait times, and overall improved driving experience.
- **Fair and Transparent Charges:** Citizens appreciate the accuracy of distance-based tolls, ensuring that they are charged fairly based on actual travel, with fewer opportunities for errors or overcharging compared to fixed toll points.

ADVANTAGES

DYNAMIC PRICING EFFICIENCY

GNSS tolling can implement dynamic pricing based on real-time traffic conditions, vehicle types, or locations. This can help in reducing congestion at toll booths and incentivizing off-peak travel, leading to more efficient toll collection and potentially lower overall costs.

DYNAMIC PRICING EFFICIENCY

With GNSS tolling, there's no need for vehicles to stop at toll booths. This improves throughput, reducing delays and the associated economic loss from waiting time at toll booths, leading to better fuel efficiency and fewer emissions.

REDUCED OPERATIONAL COSTS

: GNSS tolling eliminates the need for physical toll booths and manual collection, reducing operational and maintenance costs associated with FASTag toll systems, which require infrastructure for tag scanning, cash management, and manual oversight.

POTENTIAL DISADVANTAGES

Vulnerability to Technical Issues

Dependency on GPS Accuracy

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Financials

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Dynamic Pricing Efficiency: GNSS tolling can implement dynamic pricing based on real-time traffic conditions, vehicle types, or locations. This can help in reducing congestion at toll booths and incentivizing off-peak travel, leading to more efficient toll collection and potentially lower overall costs.

Accurate Distance-Based Charging: GNSS allows for more accurate distance-based tolling, which can ensure that vehicles are charged based on their actual travel distance and road usage. This avoids the inefficiency and inaccuracy that can arise with fixed toll points, potentially leading to fairer and more cost-effective toll collection.

ADVANTAGES

Improved Collection Efficiency: With GNSS tolling, there's no need for vehicles to stop at toll booths. This improves throughput, reducing delays and the associated economic loss from waiting time at toll booths, leading to better fuel efficiency and fewer emissions.

Reduced Operational Costs: GNSS tolling eliminates the need for physical toll booths and manual collection, reducing operational and maintenance costs associated with FASTag toll systems, which require infrastructure for tag scanning, cash management, and manual oversight.

POTENTIAL DISADVANTAGES

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IMPACT AND BENEFITS

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BENEFITS

ACCURACY IN TOLLING

By accurately distinguishing road types, the algorithm ensures precise toll charges, reducing errors and ensuring drivers are billed correctly for their actual route.

IMPROVED TRAFFIC MANAGEMENT

Enhanced tracking capabilities support more effective traffic analysis and congestion management, leading to smoother traffic flow and reduced bottlenecks.

IMPACT

PREDICTIVE ANALYTICS

By learning from historical data, the algorithm can provide predictive insights into traffic patterns, potentially aiding in traffic management and planning.

ACCURATE TRACKING IN EMERGENCIES

The ability to accurately track vehicles, even in areas with poor GNSS signals, can be critical in emergency situations, such as accidents or vehicle breakdowns. This can lead to quicker response times from emergency services.

PESTEL ANALYSIS

SOCIAL EFFECTS

Improved travel experience: The algorithm's ability to distinguish highway and service road movements can improve traffic management, provide more accurate tolling, reduce errors, and enhance driver satisfaction.

ECONOMICAL EFFECTS

Accurate GNSS-based tolling: The solution improves tolling accuracy, even with GNSS signal loss or bias, preventing overcharging or undercharging and ensuring fair revenue collection.

ENVIRONMENTAL EFFECTS

Efficient traffic flow: Accurate highway and service road distinction allows real-time rerouting, reducing congestion and emissions, contributing to a cleaner environment.

POLITICAL EFFECTS

Government partnerships: Developing AI/ML models for highway and service road distinction could spark collaborations between governments and private companies, such as automakers, tech firms, and tolling companies.

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APPLICATION GNSS TOLLING

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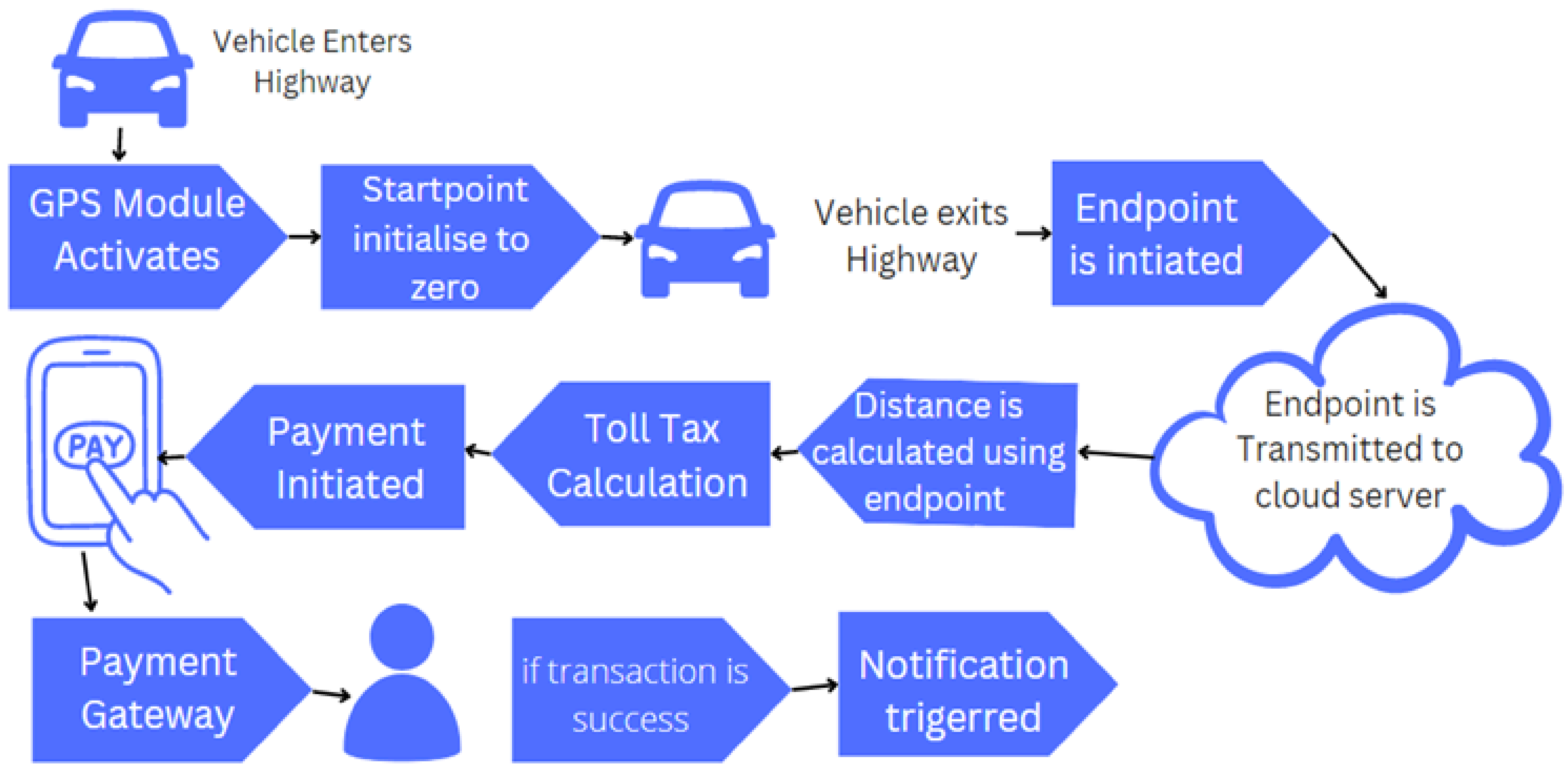
Block Diagram



What Is GNSS Tolling??

GNSS-BASED TOLLING ALLOWS FOR THE IMPLEMENTATION OF VARIOUS CHARGING SCHEMES, SUCH AS **DISTANCE-BASED TOLLING**, **TIME-BASED TOLLING**, OR **CONGESTION-BASED TOLLING**. THIS FLEXIBILITY ENABLES A FAIR AND EFFICIENT TOLL COLLECTION SYSTEM THAT CATERS TO **DIFFERENT ROAD USERS' NEEDS.**

Future Trends in GNSS-Based Tolling

- FASTER **DATA TRANSMISSION** 5G INTEGRATION
- **DYNAMIC PRICING** ON BASED OF REAL TIME DATA
- **ECO-TOLLING** (BENIFITS FOR THEESE TYPE OF VEHICLES)
- **BLOCKCHAIN FOR PAYMENTS** (SECURE TRANSACTION)

KEY COMPONENTS

- **GNSS RECEIVER** (ONBOARD UNIT): A DEVICE INSTALLED IN THE VEHICLE THAT CONTINUOUSLY COLLECTS LOCATION DATA FROM SATELLITES.
- **TELEMATICS UNIT:** A COMMUNICATION DEVICE THAT TRANSMITS THE GNSS DATA FROM THE VEHICLE TO A CENTRAL SERVER OR TOLLING SYSTEM.
- **MAP MATCHING SYSTEM:** CORRECTS RAW GNSS DATA BY MATCHING IT TO THE ROAD NETWORK, ENSURING ACCURATE ROUTE MAPPING.
- **CENTRAL SERVER:** PROCESSES DATA FROM VEHICLES, CALCULATES TOLL CHARGES, AND UPDATES BILLING INFORMATION IN REAL-TIME.
- **BILLING AND PAYMENT SYSTEM:** A PLATFORM WHERE TOLL CHARGES ARE APPLIED, AND PAYMENTS ARE PROCESSED, OFTEN THROUGH MOBILE APPS OR ELECTRONIC WALLETS.

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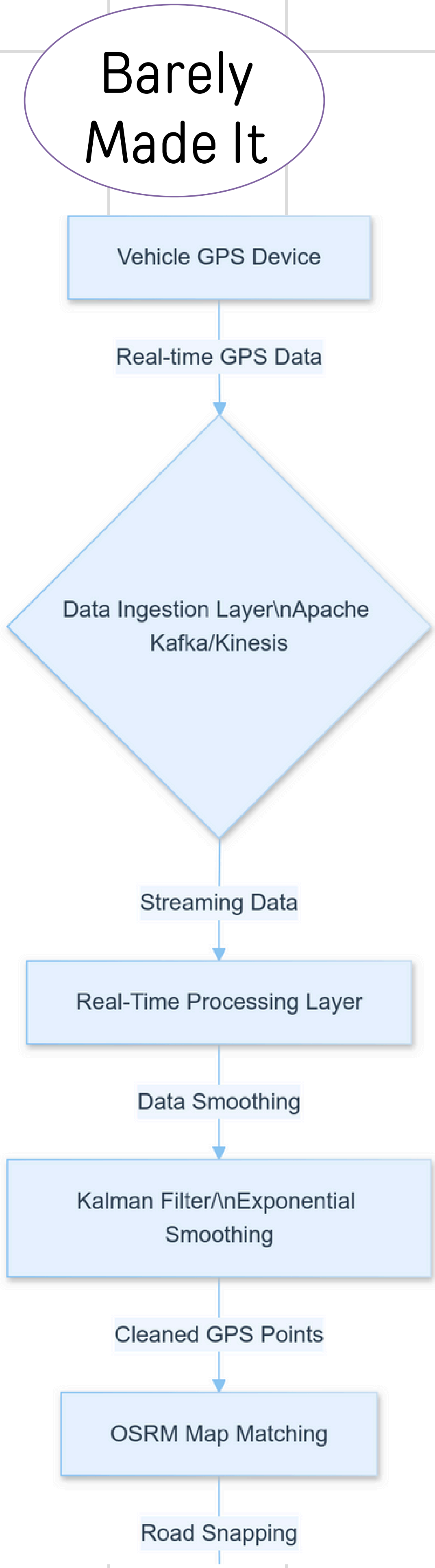
GNSS Tolling Financials

- **Revenue Increase:** The shift to GNSS-based tolling is projected to boost toll revenues by approximately **₹10,000 crore annually**. This estimate was highlighted by the Minister of Road Transport and Highways, Nitin Gadkari, indicating the substantial financial benefits expected from this modernization effort

Current Toll Collection: As of November 2023, toll collection in India had already surpassed **₹50,000 crore** for the financial year **2023-24.** This figure underscores the existing revenue potential from the current tolling systems, which GNSS aims to enhance further

Cost Efficiency: The GNSS system is designed to r**educe operational costs** associated with traditional toll booths. By eliminating physical toll plazas, the system **minimizes labor and maintenance expenses**, contributing to overall cost efficiency in toll collection operations. This reduction in overheads can lead to higher profit margins for the authorities managing these tolls

- **Cost Savings:** The new system is projected to save approximately **₹20,000 crore annually** in fuel and productivity losses due to reduced traffic congestion at toll plazas. This is attributed to the elimination of physical toll booths, which will streamline vehicle passage.



SCALABILITY

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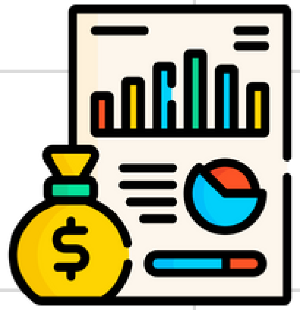

01 DATA INGESTION

- Data from vehicles is streamed directly into the **Apache Kafka** or Kinesis pipeline.
- The data is sent at **regular intervals** (every second or few seconds) and is timestamped.
- **Multiple Kafka Producers** or **Kinesis Producers** send data to a central ingestion service.

02 ROAD CLASSIFICATION

- You can use **Apache Flink** or **Apache Spark Streaming** to implement **real-time stream processing** for these operations. Both tools can process data as it arrives, applying transformations like smoothing or filtering on the fly.
- **For optimization:** you may batch some **preprocessing** steps every few seconds instead of **processing** every single GPS point in real-time.

03 TOLL CALCULATION

- **Toll Rates**: Toll rates are determined based on the **road classification** (e.g., higher tolls for highways and lower tolls for service roads).
- **Real-Time Calculation**: The system continuously calculates the toll as the vehicle moves, ensuring that **the calculation is updated as new GPS data** arrives.

04 DATA STORAGE

- Real-Time Database: **Use Apache Cassandra or Amazon DynamoDB** for storing real-time vehicle data, such as GPS coordinates, toll charges, and road classifications
- .These systems are designed to handle **large-scale, high-velocity data,** and they provide **low-latency** access, which is important for real-time processing.

05 DATA ANALYTICS

- Periodically, aggregate toll data across all vehicles and routes. This can be done using tools like **Apache Kafka** Streams or **Apache Flink,** which can compute rolling aggregates (e.g., total toll collected per day, average toll per route, etc.).

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RESEARCH AND REFERENCES

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LINKS

https://hmmlearn.readthedocs.io/en/latest/

Map Matching Technique by Uber

Hidden Markov Map Matching Through Noise and Sparseness

MIT based Map Matching and HMM research and it's application

https://project-osrm.org/docs/v5.5.1/api/#general-options

https://www.openstreetmap.org/help

TEAM

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FUTURE OUTLOOK

SCALING TO LARGER DATASETS: AS WE CONTINUE TO DEVELOP THIS ALGORITHM, WE PLAN TO EXPAND IT TO HANDLE MASSIVE DATASETS WITH MILLIONS OF DATA POINTS. THIS WILL INVOLVE ENHANCING THE ALGORITHM'S PROCESSING POWER AND INTEGRATING MORE ADVANCED AI-ML MODELS.

REAL-TIME ADAPTATION: INCORPORATING REAL-TIME GNSS CORRECTIONS AND LEARNING-BASED TECHNIQUES WILL ALLOW THE ALGORITHM TO DYNAMICALLY ADJUST, EVEN IN CHALLENGING ENVIRONMENTS, IMPROVING THE OVERALL ACCURACY.