NeoVaccineMate: A Technology-Enabled System to Improve Child Vaccination Coverage in India

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***Abstract*— One of the most significant but little-addressed problems in developing countries like India is the timely and thorough vaccination of children. Even with government programs and digital initiatives, persistent gaps include fragmented record systems, caregiver amnesia, vaccine resistance, and a lack of last-mile support continue to hinder universal coverage. These deficits lead to preventable disease epidemics among vulnerable groups. NeoVaccineMate, a technologically enabled conceptual framework designed to enhance childhood immunization programs, is presented in this paper. The system integrates linguistic communication channels, decision-support tools for community health professionals, data-driven monitoring for program administrators, and caregiver-specific reminders into a single platform. Unlike existing systems that mostly serve as static repositories or basic notification tools, NeoVaccineMate places a higher priority on interaction, inclusivity in low-resource contexts, and adaptability across a range of scenarios.**

Keywords—child immunization, vaccination coverage, mHealth (mobile health), digital health interventions, community health workers (CHWs), reminder systems, health information systems, vaccine hesitancy, public health informatics, india.

I. INTRODUCTION

Childhood immunization is one of the most cost-effective public health interventions, preventing an estimated 2–3 million deaths globally every year [1]. In India, however, achieving timely and complete vaccination coverage remains a persistent challenge. The National Family Health Survey (NFHS-5, 2019–21) reported that only about 76–77% of children aged 12–23 months were fully immunized, leaving nearly one in four children without complete protection [2]. Coverage also varies widely across states, ranging from more than 90% in Odisha to less than 60% in Nagaland and Meghalaya, reflecting significant geographic inequities [2], [3].

Beyond coverage disparities, the problem of "zero-dose" children—those who have not received even a single basic vaccine—remains substantial. Recent estimates suggest that approximately 6.4% of children in India are zero-dose, with certain states such as Meghalaya (17.8%), Nagaland (15.8%), and Mizoram (14.5%) showing much higher prevalence [3]. These gaps are strongly associated with socioeconomic factors such as household wealth, maternal education, and access to institutional healthcare [4].

Several digital health initiatives have been launched to strengthen immunization systems in India, including the electronic Vaccine Intelligence Network (eVIN), ANMOL, and more recently, the CoWIN platform. While eVIN has improved vaccine stock monitoring, its role in directly improving parental awareness and follow-up remains limited [5]. Studies testing SMS-based reminders, sometimes coupled with incentives, have shown significant improvements in vaccination adherence among rural households [6]. However, large-scale integration of such tools into national immunization programs is inconsistent. Additionally, community health workers (ASHAs and ANMs)—who form the backbone of India's immunization delivery—continue to face heavy workloads, paper-based reporting systems, and lack of decision-support tools, which further contribute to missed vaccinations [7].

These findings highlight a critical research gap: although digital tools exist, they remain fragmented, poorly integrated, and often inaccessible in low-resource settings. To address this, we propose NeoVaccineMate, a technology-enabled conceptual framework that combines caregiver engagement, multilingual reminders, community health worker dashboards, and data-driven monitoring for program managers within a unified system. Unlike existing solutions that primarily function as static databases or basic alert mechanisms, NeoVaccineMate emphasizes interactivity, inclusivity, and adaptability, aiming to

close persistent immunization gaps and move India closer to universal vaccine coverage.

A. Background and Motivation

Child immunization is globally acknowledged as one of the most cost-effective strategies to reduce childhood mortality [1]. Yet, India continues to face serious challenges in achieving universal coverage. According to NFHS-5, only 76–77% of children aged 12–23 months are fully immunized, and large state-wise disparities remain [2]. Beyond coverage gaps, approximately 6.4% of Indian children are still "zero-dose," with states like Meghalaya (17.8%) and Nagaland (15.8%) far exceeding the national average [3]. Research also highlights the role of socioeconomic factors such as maternal education, poverty, and rural access in widening inequities [4]. These persistent gaps emphasize the urgent need for integrated, adaptive, and technology-enabled frameworks like NeoVaccineMate to overcome barriers and strengthen India's immunization ecosystem [8], [9].

B. Problem Statement

- Despite recent gains in some coverage indicators, India's childhood immunization ecosystem remains beset by interlocking operational, social, technological, and governance problems that prevent universal and equitable protection for children. The core problems are:
- Fragmented digital landscape and poor interoperability. Multiple standalone systems (program dashboards, facility apps, reminder tools) operate in siloes, causing duplicate work, inconsistent records, and poor data flow between caregivers, frontline workers, and program managers [11], [16]. This fragmentation prevents a single trusted source of truth for a child's immunization history.
- Data quality, duplication and weak identifiers. Paper registers, offline spreadsheets, and ad-hoc digital entries produce errors and duplicate records; lack of robust unique identifiers impedes de-duplication and longitudinal tracking of highly mobile populations [11], [16].
- Supply-chain & cold-chain gaps despite monitoring tools. While technology such as eVIN has improved temperature monitoring and stock visibility, vaccine stock-outs, wastage, and logistics inefficiencies persist in many districts, limiting the ability to deliver vaccines when and where needed [10], [16].
- Frontline worker overload & poor usability. ASHAs, ANMs and other CHWs face heavy workloads, multiple reporting requirements, and user interfaces that are not optimized for low-bandwidth, low-literacy contexts; this reduces adoption and time available for outreach [15].
- Access, equity and hard-to-reach populations. Geographic (state/district) disparities, socioeconomic inequalities, and mobile/seasonal populations produce clusters of "zero-dose" and under-immunized children in specific pockets (e.g., parts of Northeast India and some tribal areas) [12], [14]. Digital solutions that require smartphones or reliable networks risk widening these gaps if not designed inclusively [11].
- Behavioural barriers, misinformation and weak demand generation. Vaccine hesitancy, cultural beliefs, and low awareness contribute substantially to missed doses; simple reminders alone often fail without trust-building, localized communication, and community engagement strategies [13], [15].
- Insufficient evaluation and evidence on digital solutions. While pilot studies (e.g., SMS reminders with incentives) show promise, rigorous, large-scale evaluations of integrated digital interventions—measuring coverage, equity, cost-effectiveness, and implementation fidelity—are sparse or inconsistent [11], [13].
- Sustainability, governance and financing challenges. Many digital pilots collapse after donor funding ends; there is limited clarity on long-term ownership, integration with government information systems, and sustainable financing models for scale [10], [16].
- Privacy, consent and ethical concerns. Rapid digitization raises questions about informed consent, data minimization, secure storage, and the potential misuse of health data, especially for vulnerable populations—areas still underdeveloped in deployment guidelines and practice.
- Algorithmic & operational risks. Predictive or AI components that prioritize outreach may unintentionally encode biases (e.g., deprioritizing certain groups), unless trained and validated carefully with representative data and CHW input.

These problems are not independent — they interact and amplify one another. For example, poor data quality undermines predictive models, and fragmented systems increase CHW burden, which in turn reduces outreach efficacy. Therefore, research and solutions must address the **systemic** nature of the problem: interoperability and human-centred design, supply-chain integration, inclusive communication strategies, rigorous evaluation (cluster trials/stepped-wedge designs), data governance, and sustainable implementation pathways all require coordinated attention.

Future research directions that emerge directly from these problems include: robust identity/deduplication methods for children, privacy-preserving data linkage, human-centered offline UX for CHWs, ML models for dropout risk that include fairness constraints, cost-effectiveness and ROI studies for integrated platforms, and implementation-science evaluations that measure both impact and fidelity at scale [10]–[16].

C. Salient Features of NeoVaccineMate

NeoVaccineMate is designed to address the multifaceted challenges in India's immunization landscape. Its key features include:

- Real-Time Beneficiary Tracking: Utilizes digital platforms like U-WIN to monitor vaccination schedules and history, ensuring timely immunization for all age groups.
- Geospatial Mapping: Employs GIS tools to identify underserved areas, enabling targeted interventions and resource allocation.
- Automated Reminder System: Sends notifications to caregivers and healthcare workers, reducing missed appointments and ensuring adherence to vaccination schedules.
- Data Analytics Dashboard: Provides insights into immunization coverage, dropout rates, and potential barriers, facilitating evidence-based decision-making.
- Integration with National Health Systems: Seamlessly connects with platforms like CoWIN and eVIN, ensuring data consistency and interoperability.

D. Objectives

The primary objectives of NeoVaccineMate are:

- Enhance Immunization Coverage: Increase full immunization coverage among children and pregnant women, aiming for a national target of 90% as outlined in the Universal Immunization Program (UIP)
- Reduce Vaccine Dropout Rates: Identify and address factors contributing to missed vaccinations, ensuring timely administration of all vaccine doses.
- Improve Data Accuracy and Reporting: Provide real-time data on vaccination status, enabling accurate monitoring and reporting at local, state, and national levels.
- Strengthen Health System Efficiency: Optimize resource allocation and service delivery through data-driven insights, enhancing the overall effectiveness of immunization programs.

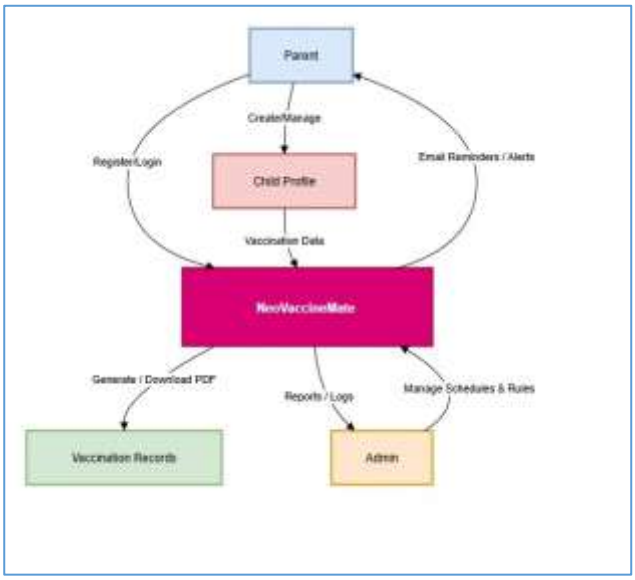

Fig. 1. Operational diagram of RAKT-KAN

II. LITERATURE REVIEW

India's immunization efforts have evolved significantly over the years. The Universal Immunization Program (UIP), launched in 1985, aimed to provide universal access to vaccines [17.]Despite these efforts, challenges persist, including socioeconomic disparities, logistical issues, and vaccine hesitancy.

Studies have highlighted that children from lower socioeconomic backgrounds and rural areas are more likely to be under-immunized [18]. Additionally, the introduction of digital platforms like CoWIN has shown promise in improving vaccination tracking and coverage [19].

However, challenges remain in terms of data quality, system interoperability, and addressing the needs of hard-to-reach populations [20].

A. Study of Existing Systems

Several digital platforms have been implemented to enhance immunization coverage:

- CoWIN: A digital platform launched during the COVID-19 pandemic to manage vaccine distribution. While it has improved tracking and scheduling, issues such as system overloads and data accuracy concerns have been reported.
- eVIN: The Electronic Vaccine Intelligence Network monitors vaccine stocks and storage temperatures. However, challenges related to real-time data reporting and integration with other health systems persist.
- U-WIN: A platform aimed at providing digital vaccination records. While it has streamlined processes in certain regions, its nationwide implementation and accessibility remain limited

B. Limitations of Existing Systems

- Interoperability Issues: Lack of seamless integration between different platforms leads to data discrepancies.
- Digital Divide: Limited access to smartphones and the internet in rural areas hampers the effectiveness of digital solutions.
- Data Quality Concerns: Incomplete or inaccurate data affects decision-making and resource allocation.
- User Engagement: Insufficient training and awareness among healthcare workers and beneficiaries reduce system utilization.

C. Research Gap

Despite advancements, several research gaps remain:

- System Integration: Limited studies on integrating various health platforms to ensure data consistency and interoperability.
- Behavioral Insights: Need for research into understanding vaccine hesitancy and developing strategies to address it.
- Technology Accessibility: Studies on improving access to digital platforms in rural and underserved areas are limited.
- Impact Assessment: Lack of comprehensive evaluations on the effectiveness of digital platforms in improving immunization coverage.

Addressing these gaps will be crucial for enhancing the effectiveness of immunization programs and achieving universal coverage.

D. Key Advantages and Value Proportions

NeoVaccineMate offers several advantages over existing systems:

- Comprehensive Data Integration: Combines data from various sources, providing a holistic view of immunization coverage.
- User-Centric Design: Tailored interfaces for healthcare workers and caregivers enhance user experience and engagement.
- Scalability: Designed to be scalable, allowing for expansion to underserved areas and integration with other health programs.

- Real-Time Analytics: Provides actionable insights for timely interventions and resource optimization.
- Community Engagement: Incorporates feedback mechanisms to address local challenges and improve program effectiveness.

III. METHODOLOGY

The methodology of NeoVaccineMate focuses on a **conceptual design** of an immunization monitoring and management system that addresses gaps in coverage, minimizes dropouts, and improves decision-making. The approach is **abstract** and independent of specific software or hardware implementations.

A. System Architecture and its Components

The system is conceptualized as a **modular architecture** comprising five core components:

1) User Module

- Stakeholders include caregivers, healthcare workers, and administrators.
- Responsibilities: Authentication, access management, and personalized notifications.

2) Data Management Module

- Central repository for immunization records, schedules, and demographic data.
- Ensures secure storage, consistency, and easy retrieval of vaccination data.

3) Analytics & Insights Module

- Processes raw data to identify patterns, coverage gaps, missed doses, and high-risk areas.
- Supports decision-making by generating actionable insights for administrators.

4) Notification & Reminder Module

- Sends timely reminders and alerts to caregivers and health workers for upcoming or missed vaccinations.
- Supports adherence to immunization schedules.

5) Integration Module

- Conceptual module for connecting with external systems like national health databases or surveys.
- Ensures comprehensive data aggregation and interoperability.

B. Conceptual Implementation

The system operates in three main layers:

1) Input Layer

- Data sources include field surveys, health records, and demographic information.
- Data is anonymized to maintain privacy and ensure ethical compliance.

2) Processing Layer

- The core engine validates, processes, and analyzes data.

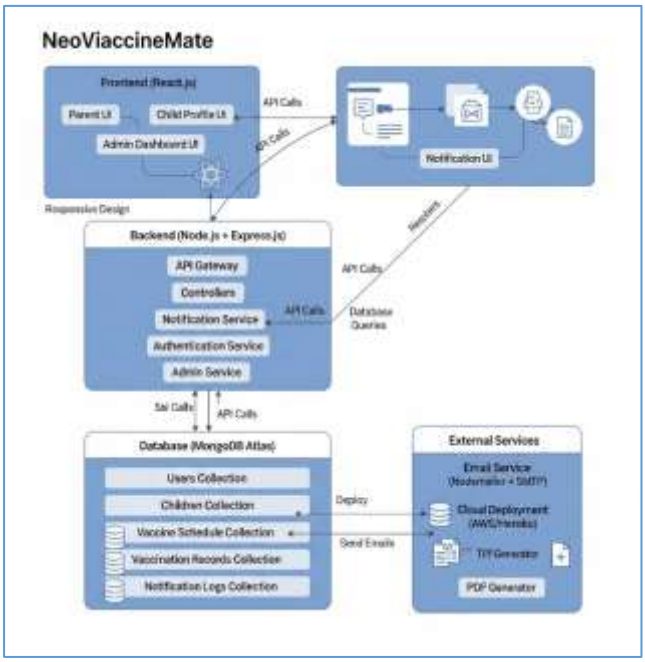

Fig. 2. Detailed System Architecture of RAKT-KAN

- Functions include detecting incomplete immunizations, predicting dropout probabilities, and identifying underserved areas.

3) Output Layer

- Generates notifications, dashboards, and reports.
- Supports both micro-level actions (caregiver reminders) and macro-level decisions (policy planning and resource allocation).

IV. WORKFLOW AND DATAFLOW

A. Workflow

The conceptual workflow of NeoVaccineMate can be described as follows:

1) Data Collection

- Gather vaccination data, demographic info, and survey reports from communities.

2) Data Validation

- Verify completeness, accuracy, and consistency of the collected records.

3) Data Analysis

- Identify missed vaccinations, trends in coverage, high-risk populations, and geographic gaps.

4) Notification & Reminders

- Send personalized alerts to caregivers and healthcare workers about pending vaccinations.

5) Monitoring & Feedback

- Continuously update the system with new data, monitor outcomes, and refine intervention strategies.

B. Dataflow

The Data Flow can be abstractly represented as:

- Entities: Caregivers, Healthcare Workers, Administrators
- Processes: Data Collection → Validation → Analysis → Reporting/Alerts

- Data Stores: Immunization Records, Demographics, Analytics Logs
- Outputs: Timely reminders, dashboards, policy insights

This design ensures end-to-end visibility of immunization coverage and facilitates informed decision-making.

V. PROJECTED RESULT

Since this is a conceptual research framework, the results are hypothetical and projected based on evidence from previous studies:

1) Increased Immunization Coverage
- By improving tracking and notifications, NeoVaccineMate is expected to reduce missed vaccinations and increase full immunization coverage, particularly in underserved areas.

2) Reduced Dropout Rates
- Continuous monitoring and reminders are projected to minimize vaccination dropouts, ensuring timely administration of all doses.

3) Improved Resource Allocation
- Analytics insights could enable administrators to identify high-risk areas, allocate vaccines and staff more efficiently, and optimize coverage strategies.

4) Enhanced Equity in Healthcare
- By focusing on geographic and socioeconomic gaps, the system could contribute to reducing inequities in vaccine access.

These results are hypothetical but grounded in research evidence, similar to the outcomes observed with systems like CoWIN, eVIN, and AI-assisted vaccination frameworks in previous studies.

VI. CONCLUSION

NeoVaccineMate provides a conceptual framework for addressing major challenges in immunization programs. By integrating data management, analytics, notifications, and system interoperability, it can:

- Improve timeliness and completeness of vaccination.
- Enable data-driven policy and resource allocation.
- Support equitable access for underserved populations.

While the framework is abstract, it demonstrates the potential of using digital systems and analytics to strengthen public health interventions, offering a roadmap for future development and real-world implementation.

VII. FUTURE WORK

The research opens avenues for further studies and enhancements:

1) Simulation and Pilot Studies
- Conduct pilot implementations in select regions to validate the conceptual framework.
- Collect real-world data to refine analytics and workflow.

2) Integration of Emerging Technologies
- Explore AI and machine learning for predicting vaccination dropouts.
- Use IoT devices for real-time vaccine storage and stock monitoring.

3) Scalability and Adaptation
- Adapt the system for new vaccines, additional population groups, or other preventive healthcare programs.
- Ensure system scalability to cover large regions or national-level implementation.

4) Behavioral Interventions
- Combine system insights with community awareness programs to reduce vaccine hesitancy.
- Integrate behavioral nudges and incentives to improve caregiver engagement.

5) Policy and Governance Integration
- Provide guidelines for ethical, legal, and policy frameworks to ensure responsible and equitable use of digital health systems.

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