Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Child Health Care and Immunization Reminder: Design and Implementation of a Web-Based Immunization Reminder and Child Health Record System for Low-Resource Settings

Md. Shohag Mia
International Islamic University Chittagong
Md. Arifur Rahman
International Islamic University Chittagong
Baizid MD Ashadzzaman
baizid.md.ashadzzaman@gmail.com

International Islamic University Chittagong https://orcid.org/0009-0008-4137-5905

Research Article

Keywords: immunization reminder, childhood vaccination, e-health, SMS reminder, immunization information system, Bangladesh, low- and middle-income countries

Posted Date: November 6th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11631750/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: The authors declare no competing interests.

Child Health Care and Immunization Reminder: Design and Implementation of a Web-Based Immunization Reminder and Child Health Record System for Low-Resource Settings

Md. Shohag Mia[1], **Md. Arifur Rahman**[1]

[1] Department of Computer Science and Engineering, International Islamic University Chittagong (IIUC), Chattogram, Bangladesh

Abstract

Routine childhood immunization is one of the most cost-effective public health interventions available, and Bangladesh's Expanded Programme on Immunization (EPI) is widely regarded as a success story, maintaining third-dose pentavalent coverage of approximately 98% in recent years. Nevertheless, national aggregates conceal important pockets of zero-dose and under-immunized children, and dose timeliness remains imperfect: recent survey evidence finds 1.9% zero-dose and 11.6% under-immunized children nationally, with markedly higher rates in wetland (haor) areas, coastal belts, and urban slums. Caregiver-level barriers—forgotten appointments, competing demands, and paper-based child health cards that are easily lost—are frequently cited contributors to missed doses. A substantial body of evidence shows that patient reminder and recall interventions measurably increase vaccination uptake, with systematic reviews of low- and middle-income countries (LMICs) reporting relative increases of 9–16% for text-message reminders. This paper presents the design, implementation, and functional evaluation of the Child Health Care and Immunization Reminder (CHCIR) system, a web-based platform that maintains digitized child immunization records, computes per-child vaccination due dates from the national EPI schedule, and dispatches automated short-message service (SMS) and e-mail reminders to guardians. The system follows a three-tier architecture built on the Microsoft .NET technology stack with a relational back end normalized to third normal form, and it supports three stakeholder roles—administrator, field employee, and guardian—through role-based access control. Security measures include salted password hashing, parameterized database access, anti-CSRF tokens, and output encoding against cross-site scripting. The system was verified through unit, integration, and system testing with all functional test cases passing. The CHCIR system demonstrates that an individually targeted, schedule-aware reminder capability can be engineered at low cost atop infrastructure that already reaches more than 190 million mobile subscriptions in Bangladesh, making it a plausible complement to national defaulter-tracing efforts. Field evaluation of vaccination-coverage impact remains an important next step.

Keywords: immunization reminder, childhood vaccination, e-health, SMS reminder, immunization information system, Bangladesh, low- and middle-income countries

1. Introduction

Immunization averts an estimated 3.5–5 million deaths every year from diseases such as diphtheria, tetanus, pertussis, measles, and polio, and the World Health Organization's Expanded Programme on Immunization, established in 1974, remains the principal global vehicle for delivering routine childhood vaccines [1]. Bangladesh launched its national EPI in 1979 and, after a period of very low initial coverage, scaled the programme nationwide between 1985 and 1990 [2]. The programme now targets approximately 3.8 million children born each year with a schedule of ten vaccines, and its administrative coverage figures are strong by regional standards: WHO and UNICEF estimates place BCG coverage at 99% and third-dose pentavalent (DTP3) coverage at 98% for 2023, with first- and second-dose measles-containing vaccine coverage at 97% and 93% respectively [3].

Strong national averages, however, mask two persistent problems. The first is geographic and socioeconomic inequity in access. A recent large cluster survey covering 12 sub-districts and more than 12,000 caregivers estimated that 1.9% of Bangladeshi children were zero-dose (having received no pentavalent dose) and 11.6% were under-immunized, with the burden concentrated in hard-to-reach ecologies: 21.3% of children in haor wetland areas were zero-dose or under-immunized, and children in urban slums, coastal areas, and haor were roughly two to three times more likely to be zero-dose than children in plain rural areas [2]. The second problem is timeliness and completeness at the individual level. The Bangladesh Demographic and Health Survey-aligned Coverage Evaluation Survey 2023 reported valid full vaccination coverage of 81.6%—substantially below the approximately 98% administrative DTP3 figure—indicating that many children are vaccinated late or with delayed doses even when they eventually complete the schedule [4]. Globally, an estimated 14.3 million infants received no doses of DTP in 2023 [5].

At the caregiver level, the causes of missed and delayed doses are well documented and largely behavioral and logistical rather than vaccine-hesitancy driven: forgotten appointment dates, loss or damage of the paper-based child health card, distance and transport costs, concurrent childhood illness, and the competing time pressures facing mothers and other caregivers [2], [6]. These causes share a common structure—the caregiver's intention to vaccinate exists, but the timely cue to act does not. This is precisely the failure mode that reminder and recall interventions address.

The evidence base for reminders is mature. The Cochrane review of patient reminder and recall interventions, covering 75 studies and over 138,000 participants, found that approximately 8% more people were vaccinated when reminded than when not, with high-certainty evidence that postcards, text messages, and automated telephone calls are all effective delivery modalities [6]. Effect sizes in LMIC settings, where the residual coverage

gap is concentrated, appear at least as large: a systematic review and meta-analysis of 18 studies covering 32,712 infants in 11 LMICs found that SMS reminders significantly improved immunization coverage (relative risk [RR] 1.16, 95% confidence interval [CI] 1.10–1.21) and timeliness (RR 1.21, 95% CI 1.12–1.30), with significantly larger effects in low- and lower-middle-income countries than in upper-middle-income countries [7]. Other meta-analyses report more conservative pooled estimates—RR 1.11 (95% CI 1.05–1.17) across 10 randomized trials [8] and RR 1.09 (95% CI 1.06–1.13) across 25 randomized trials [9]—reinforcing that the effect is real but modest and sensitive to intervention design. Notably, the LMIC-focused Cochrane review of interventions for improving childhood immunization coverage found only low-certainty evidence of benefit from phone calls and short messages alone (RR 1.12, 95% CI 1.00–1.25) while finding larger effects for health education and home-based records [10], and the meta-analysis by Eze et al. found that sending more than two reminders significantly improved timeliness [7]—both findings argue for reminder systems that are schedule-aware and multi-touch rather than single-shot.

Bangladesh has direct proof of concept. The mTika project evaluated an Android- and web-based system integrated with the government EPI that registered births, generated individualized vaccination timetables, and sent three SMS reminders per dose to guardians in a rural hard-to-reach district and in urban street-dwelling communities. Full vaccination coverage rose from 58.9% to 76.8% in rural intervention sites and from 40.7% to 57.1% in urban intervention sites over one year, while coverage fell in control sites [11]. This demonstration establishes that schedule-driven, individually targeted reminders can move coverage in the exact populations where the residual gap lives.

What remains under-served is a general-purpose, configurable information system that a district health team or a non-governmental provider can deploy to digitize child records and run reminders as routine business—rather than as a time-bounded research project. Paper records still dominate at many service delivery points; defaulter lists are reconstructed by hand, if at all; and reminder campaigns, where they exist, tend to be broadcast messages rather than individually scheduled cues keyed to each child's own date of birth and dose history.

This paper presents the Child Health Care and Immunization Reminder (CHCIR) system, a web-based platform designed and implemented to close that gap. The system's objectives are to: (1) maintain a digitized, individually indexed record of every enrolled child's immunization history; (2) automatically compute per-child dose due dates from the configurable national EPI schedule; (3) dispatch automated SMS and e-mail reminders to guardians before each due date and escalate after missed doses; (4) support coordinated reminder and information campaigns; and (5) do so with security and access-control appropriate to children's health data. The principal contributions of this paper are:

1. A requirements analysis and three-tier system design for an EPI-aligned immunization reminder platform suitable for LMIC deployment, grounded in the documented characteristics of the Bangladeshi immunization landscape.

2. A schedule engine that derives per-child reminder timelines from a database-configurable representation of the national immunization schedule, so that programme changes—such as the introduction of new antigens—require configuration rather than reprogramming.
3. A security design for a multi-role e-health system handling minors' protected health data, addressing injection, CSRF, XSS, and access-control threats.
4. A functional evaluation of the implemented prototype through unit, integration, and system testing, together with an explicit discussion of limitations, including the absence of a field trial.

The remainder of this paper is organized as follows. Section 2 reviews related work on reminder interventions and immunization information systems. Section 3 presents the requirements analysis and feasibility assessment. Section 4 describes the system design, including architecture, data model, and the reminder scheduling algorithm. Section 5 covers implementation. Section 6 details the security design. Section 7 reports the testing regime. Section 8 discusses the results and limitations, and Section 9 concludes with future work.

2. Background and Related Work

2.1 Reminder and recall interventions: the general evidence

Reminder and recall interventions—cues to attend a scheduled appointment (reminders) and active follow-up when an appointment is missed (recall)—have been studied for over four decades across outpatient settings, with vaccination among the best-evidenced applications. The definitive Cochrane synthesis by Jacobson Vann et al. pooled 75 studies from 10 countries, involving 138,625 participants, and found an average absolute increase of about 8 percentage points in vaccination among reminded individuals, with similar effect sizes for children and adults [6]. Delivery modality mattered less than the existence of the cue itself: postcards, text messages, and automated telephone calls all showed high-certainty benefit, though telephone reminders showed the largest effects. The review also found that reminders were effective across a range of target populations, supporting the generalizability of the approach rather than its confinement to any single setting.

2.2 Text-message reminders in low- and middle-income countries

Because SMS delivery requires only basic mobile telephony—no smartphone, no data plan, and no literacy beyond the message itself—text-message reminders are the modality of choice for LMIC deployment, where the world's remaining zero-dose children are concentrated. The pooled evidence specific to LMICs is favorable but instructively heterogeneous.

Eze et al. conducted the most directly relevant meta-analysis, pooling 18 studies (13 randomized and 5 non-randomized) covering 32,712 infants across 11 LMICs [7]. SMS reminders improved both coverage (RR 1.16, 95% CI 1.10–1.21) and timeliness (RR 1.21, 95% CI 1.12–1.30). Two design findings from that review directly shape the present work: effects

were significantly larger in low- and lower-middle-income countries than in upper-middle-income countries ($p < 0.001$), and interventions sending more than two reminders achieved significantly better timeliness ($p = 0.040$). Earlier and later syntheses report attenuated but consistent effects: Mekonnen et al. pooled 10 randomized trials at RR 1.11 (95% CI 1.05–1.17) [8], and Louw et al., pooling 25 randomized trials judged at low risk of bias, found RR 1.09 (95% CI 1.06–1.13), with no significant modification of effect by country income status or intervention characteristics [9]. Against this backdrop, the Cochrane review of childhood immunization interventions in LMICs found the phone/SMS evidence base to be positive but of low certainty for DTP3/Penta3 completion specifically (RR 1.12, 95% CI 1.00–1.25; 6 studies; 3,869 participants), while health education (RR 1.36) and home-based records (RR 1.36)—also low-certainty—showed larger point estimates [10]. The reasonable reading, which informs our design, is that reminders are a reliable but insufficient instrument: they work best as part of a system that also maintains an accurate individual record and supports counselling.

2.3 Immunization reminder systems in Bangladesh

The strongest regional precedent is mTika, evaluated by Uddin et al. in a quasi-experimental pre-post design conducted from April 2013 to March 2014 in Sunamganj district—a remote haor (wetland) area—and two Dhaka City Corporation zones serving street-dwelling populations [11]. The mTika platform registered births, produced child-specific vaccination timetables, and sent three SMS reminders per dose (one day before the session, at session opening, and two hours before session closing), using barcode- and symbol-based messages for guardians with limited literacy. In rural intervention sites, full vaccination coverage increased from 58.9% to 76.8% (increase 18.8%, 95% CI 5.7–31.9); in urban street-dweller sites, from 40.7% to 57.1% (increase 16.5%, 95% CI 3.9–29.0); coverage declined in concurrent control sites. Difference-in-differences estimates were +29.5% (rural) and +27.1% (urban), with adjusted odds ratios of 3.8 (95% CI 1.5–9.2) and 3.0 (95% CI 1.4–6.4) respectively. An earlier multi-intervention project in the same hard-to-reach district similarly reported gains from combined outreach and communication efforts [12]. These studies establish local efficacy for reminder components; they were, however, project-based implementations tied to specific research deployments, and none offers a general-purpose platform that other districts or organizations can adopt, configure to the current national schedule, and operate as routine infrastructure. That adoption gap is the niche the CHCIR system addresses.

2.4 Immunization information systems

High-income countries have long operated immunization information systems (IIS)—centralized registries that consolidate doses from all providers, generate reminder/recall lists, and support programme management. The LMIC analogue is typically far thinner: paper-based tally sheets and child cards, with aggregation at the facility level and little individual-level follow-up infrastructure. Digital individual-level systems are emerging—mTika in Bangladesh, Smart Health BD's community health platform, and OpenSRP-based deployments elsewhere—but coverage is partial and fragmentation is common. The design

goal of CHCIR is deliberately modest relative to a national IIS: a deployable, self-hostable web platform that any district or non-governmental service provider can run to manage its own enrolled cohort, generate individualized reminder schedules aligned to the national EPI timetable, and export coverage reports. Where national digital infrastructure exists, the system's tabular, normalized data model is intended to permit later integration rather than to compete with it.

3. Requirements Analysis and Feasibility

3.1 Stakeholders and user classes

Analysis of the immunization service delivery chain identified three principal user classes:

- **Administrator.** A programme manager with full authority over the deployment: creating and suspending user accounts for employees and guardians, assigning roles, configuring system settings (reminder lead times, sender identifiers, message templates), maintaining the vaccine and schedule configuration tables, launching campaigns, and viewing all reports and activity logs.
- **Employee.** A field or facility-level health worker who performs the daily transactional work: enrolling guardians and registering children with date of birth and demographic details, recording administered doses against the child's record, monitoring pending and overdue reminders, handling inbound guardian queries, and viewing campaign status.
- **Guardian (parent).** The child's parent or caregiver, who registers with a mobile number and e-mail address, maintains contact details, views each enrolled child's immunization record and upcoming due dates, and receives automated SMS and e-mail reminders.

External actors outside the trust boundary are the SMS gateway provider, which delivers outbound messages over an HTTP API, and the e-mail service used for parallel electronic notification.

3.2 Functional requirements

The functional requirements derived from the analysis are summarized in Table 1. They reflect the two core jobs of the system—maintaining the individual record and driving the reminder cycle—plus the administrative and reporting functions required to operate it as routine business.

Table 1. Principal functional requirements.

ID	Requirement
FR1	The system shall allow authenticated employees to create, read, update, and delete guardian and child registration records.
FR2	The system shall maintain, for every registered child, an immunization record linking each scheduled antigen to its due date

ID	Requirement
	and administration status.
FR3	The system shall compute per-child dose due dates automatically from the configured national immunization schedule and the child's date of birth.
FR4	The system shall dispatch automated SMS and e-mail reminders to registered guardians ahead of each upcoming dose and shall escalate recall messages for overdue doses.
FR5	The system shall record the delivery status of every dispatched notification for audit and follow-up.
FR6	The system shall allow administrators to compose and schedule reminder and information campaigns targeted at selected cohorts.
FR7	The system shall support role-based creation, assignment, and revocation of user accounts.
FR8	The system shall provide dashboards per role: system status and reports for administrators, caseload and pending-reminder queues for employees, and per-child schedules for guardians.
FR9	The system shall generate coverage and defaulter reports for arbitrary date ranges and administrative areas.
FR10	The system shall maintain an activity log of security-relevant and data-changing operations.
FR11	The system shall allow administrators to modify the vaccine and schedule configuration tables without code changes (FR3 depends on this).
FR12	The system shall provide an authenticated logout facility and enforce session expiry.

3.3 Non-functional requirements

The system's intended operating environment imposes a distinctive set of non-functional constraints. **Availability and reach** are paramount: deployment targets contexts where connectivity may be intermittent, so the application must degrade gracefully and retry failed notifications rather than losing them. **Operational simplicity** is a hard requirement—the system will be administered by health programme staff, not by professional system administrators, so installation, backup, and routine operation must fit on commodity hardware with managed commercial database software. **Usability** must accommodate users with limited computer literacy: plain forms, minimal navigation depth, and clear status indicators. **Security and privacy** are non-negotiable given that the system stores identifiable health data about minors (Section 6). **Scalability** requirements are modest in absolute terms—a single deployment typically manages thousands rather than millions of children—but reminder dispatch must still complete within a bounded window

for an entire enrolled cohort on reminder days. **Configurability** (FR11) is required so that schedule changes such as antigen introductions do not necessitate developer intervention.

The requirement classes used to structure this analysis are summarized in Figure 1: beyond the functional behaviour captured in Table 1, the analysis separately considered performance, interface, maintainability, reliability, safety, quality, operational, and resource constraints, each of which produced concrete design decisions reported in later sections.



Figure 1: Categories of specification used to structure the requirements analysis.

3.4 Feasibility

Technical feasibility. The system is built entirely from widely available commercial and off-the-shelf components: the Microsoft .NET web stack hosted on Internet Information Services (IIS), a relational database server, and standard SMS-gateway HTTP APIs. All components are supported on commodity server hardware; the baseline requirements (a multicore processor, 2 GB RAM, and a few gigabytes of storage) are easily met by entry-level cloud instances or on-premises servers, and the same stack is in routine use across

Bangladeshi government and commercial deployments, ensuring a local maintenance talent pool.

Economic feasibility. Costs fall into one-time development (absorbed as part of the project described here) and recurring operation: SMS-gateway per-message charges, server hosting, and domain/SSL fees. SMS pricing in Bangladesh is low relative to programme budgets, and the reminder logic in Section 4 sends a bounded number of messages per child per dose (Section 4.4), keeping per-child annual messaging cost to a few dozen messages—trivial beside the cost of a missed-dose recall visit or an avoidable disease episode. Because the platform eliminates paper forms, manual defaulter-list reconstruction, and long-form letter campaigns, operational savings partially offset message costs.

Operational feasibility. The system slots into existing workflows rather than replacing them: employees continue vaccinating as before and simply record doses in the system, while the reminder cycle, previously dependent on guardian memory and paper cards, is automated. Guardians need only a mobile phone to benefit; Bangladesh's 190.44 million mobile subscriptions and 121.52 million mobile-internet subscriptions as of mid-2026 [13] indicate that SMS reach approaches universal coverage among the target population, though multi-SIM ownership means subscriptions should be read as an upper bound on unique reach.

4. System Design

4.1 Architecture

CHCIR follows a classic three-tier web architecture separating presentation, business logic, and data storage, with two integration points at the back end: the SMS gateway and the scheduled reminder engine.

- **Presentation tier.** Server-rendered pages plus an AngularJS single-page-application layer for the interactive dashboards, styled with Bootstrap for responsive layout on both desktop and low-end mobile browsers. All interaction with the business tier occurs through AJAX calls to controller endpoints.
- **Application tier.** ASP.NET controllers implement the use cases of Section 3. Business services encapsulate the domain logic: registration, dose recording, the schedule engine (Section 4.4), campaign management, reporting, and notification orchestration. A background scheduler component triggers reminder evaluation at configured intervals.
- **Data tier.** A relational database (Microsoft SQL Server) stores all persistent state per the schema of Section 4.3, accessed exclusively through parameterized queries.
- **Integration tier.** An SMS-gateway adapter presents a uniform internal interface over the provider's HTTP API, isolating the rest of the system from provider-specific payloads; an e-mail adapter provides parallel notification.

The separation of the schedule engine into its own service module is a deliberate design choice: it isolates the only component whose logic must change when national policy changes, and it allows reminder evaluation to run as a scheduled batch without touching the interactive request path.

4.2 Use cases

The use cases follow directly from the user classes. Administrators perform *Manage Users* (create/edit/suspend accounts, assign roles), *Configure System* (reminder lead times, templates, vaccine schedule tables), *Launch Campaign*, and *View Reports*. Employees perform *Register Guardian*, *Register Child*, *Record Immunization Dose*, *Monitor Reminder Queue*, and *Respond to Query*. Guardians perform *View Child Record*, *View Upcoming Due Dates*, and *Update Contact Details*. The critical automated use case is *Evaluate and Dispatch Reminders*, executed by the scheduler: it queries for children with doses entering the reminder window, generates personalized messages from templates, hands them to the SMS adapter, and writes notification-log entries. The primary invariants enforced across use cases are that employees may modify only records within their scope, guardians may read only their own children's records, and only administrators may alter schedule configuration or accounts.

Figure 2 shows the interaction sequence for the authentication use case, which every other use case depends on: credentials supplied at the presentation tier are validated by the application tier against the credential store in the data tier, and only a successful match yields a session whose role determines the subsequent navigation surface.

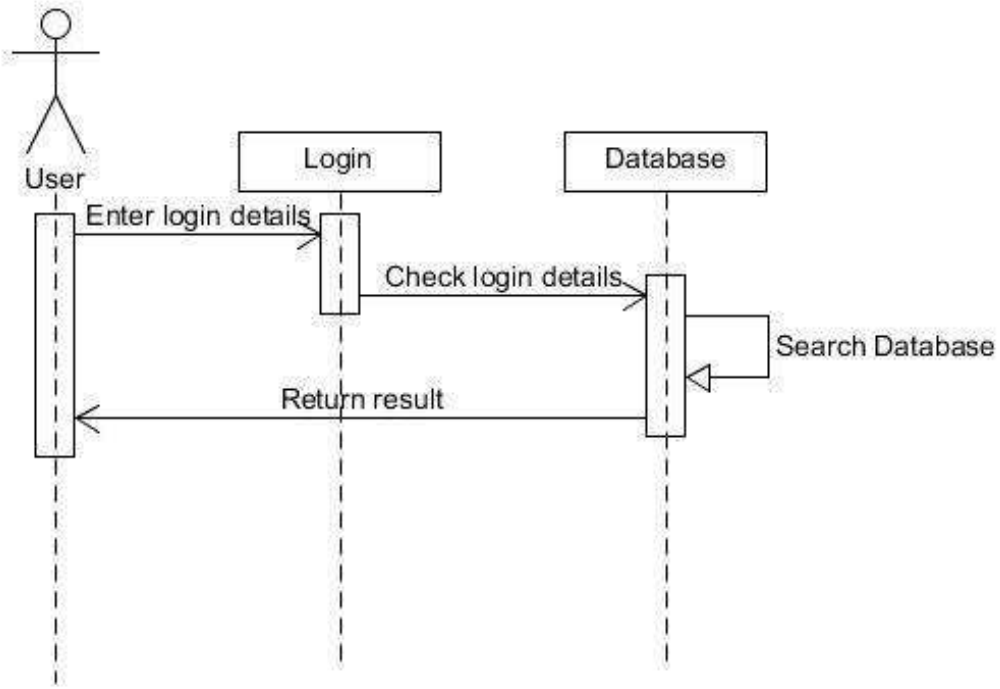


Figure 2: Sequence diagram of the login use case.

4.3 Data model

The entity-relationship model was normalized to third normal form to eliminate insertion, deletion, and update anomalies. The principal entities and their relationships are summarized below.

users (user_id PK, role, full_name, mobile_no, email, password_hash, status, created_at) — one row per account of any role. Role ∈ {admin, employee, guardian}.

guardians (guardian_id PK, user_id FK → users, address, upazila, district) — guardian profile details; a guardian user may have zero or more children.

children (child_id PK, guardian_id FK → guardians, full_name, date_of_birth, sex, birth_weight, registered_by FK → users, created_at) — the central record. Date of birth is the anchor for all schedule computation.

vaccines (vaccine_id PK, name, description, dose_count) — reference data for antigens in the national schedule (e.g., BCG, OPV, pentavalent, PCV, fractional IPV, measles-rubella, Td).

schedule_entries (schedule_id PK, vaccine_id FK → vaccines, dose_no, due_age_weeks, lead_time_days) — the configurable EPI schedule. Each entry states that dose *n* of a vaccine is due at a child's age of *due_age_weeks* weeks, with reminders beginning

lead_time_days before that date. This table is the data-driven representation of the national schedule and is maintained through FR11.

immunization_records (record_id PK, child_id FK → children, vaccine_id FK → vaccines, dose_no, due_date, status, administered_date, administered_by FK → users, remarks) — one row per (child, vaccine, dose), instantiated by the schedule engine at child registration. Status ∈ {scheduled, administered, overdue, skipped}.

reminders (reminder_id PK, record_id FK → immunization_records, reminder_type, scheduled_at, dispatched_at, channel, delivery_status) — one row per planned or sent message, giving FR5's audit trail. Reminder_type ∈ {advance, due, recall}.

campaigns (campaign_id PK, title, message_template, target_criteria, scheduled_at, created_by FK → users, status) — bulk messaging for information campaigns and special drives.

activity_log (log_id PK, user_id FK → users, action, entity, entity_id, timestamp) — the audit trail required by FR10.

The relationships are all foreign-key-enforced: a guardian 1:N children; a child 1:N immunization_records (one per scheduled dose); a vaccine 1:N schedule_entries and 1:N immunization_records; an immunization_record 1:N reminders. Storing computed due dates on immunization_records rather than recomputing them at query time trades a small amount of redundancy for simple, fast reporting queries and a stable audit trail; the redundancy is controlled because due dates are written once at instantiation and updated only through defined dose-recording transactions.

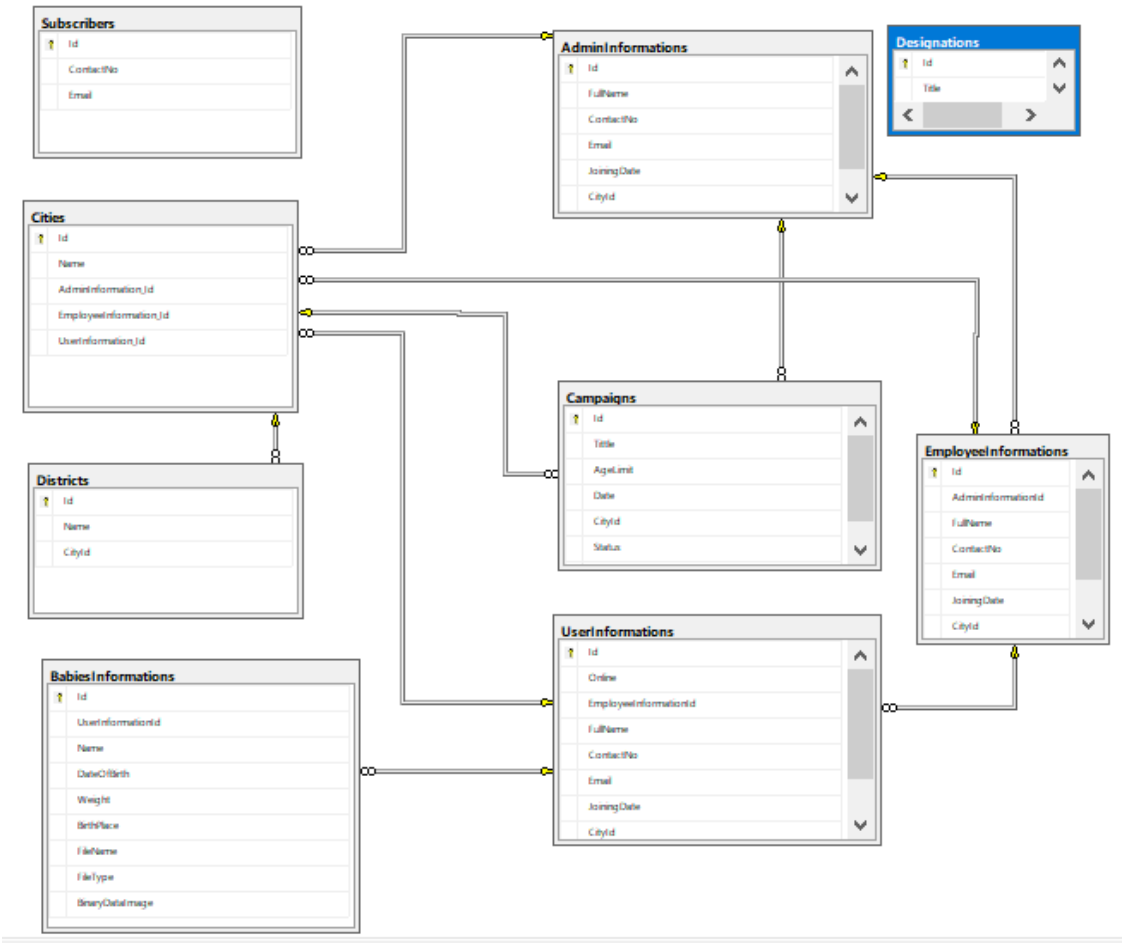


Figure 3: Entity-relationship diagram of the implemented database schema.

4.4 The schedule engine and reminder algorithm

The schedule engine is the system's distinctive component. On guardian registration of a child (date of birth *DOB*), the engine instantiates the child's immunization plan by joining the child's record against every row of schedule_entries, computing for each (vaccine, dose) pair:

```
due_date(vaccine, dose) = DOB + due_age_weeks(vaccine, dose) × 7 days
```

For each instantiated record the engine then materializes the reminder rows demanded by the policy in FR4: an **advance** reminder at `due_date − lead_time_days`, a **due** reminder on `due_date`, and—if the record remains in status *scheduled* past due_date—a **recall** reminder escalating the message to overdue framing. Because reminders are rows in the database scheduled ahead of time, dispatch is a simple periodic sweep rather than real-time computation, which bounds the reminder-day workload and makes retries after connectivity outages natural.

This design encodes three evidence-informed choices. First, multiple reminders per dose follow Eze et al.'s finding that more than two messages significantly improve timeliness [7] and the three-per-dose protocol of the mTika trial [11]. Second, recall escalation after a missed dose addresses the fact that the highest-yield moment for a lapsed appointment is shortly after it lapses. Third, all timing parameters—lead time, which channels fire, message wording—live in configuration tables, so a programme can tune cadence and wording without deployment, and schedule changes (new antigens, changed ages) are data edits.

Message templates support variable substitution (child name, vaccine, due date, nearest facility), and the system renders both Bangla and English message variants. For guardians with limited literacy, the message body is kept short and includes the date in numeric form, following the accessibility lesson from mTika's symbol-based messaging [11]; voice/IVR delivery is identified as future work (Section 9).

4.5 User interface design

Three dashboards implement the per-role views of FR8. The administrator dashboard presents user management, schedule configuration, campaign composition, and system-wide reports. The employee dashboard front-loads the daily work queue—children newly due, reminders dispatched, doses overdue—with direct actions to record doses and enroll children. The guardian view presents each enrolled child's simple timeline of completed and upcoming doses with the next due date emphasized, and allows contact-detail maintenance. Navigation is limited to at most two clicks from any dashboard to any frequently used function, and all list views are filterable by area and date to support supervisory use.

5. Implementation

5.1 Technology stack

The implemented prototype uses ASP.NET on the .NET Framework with C# for server-side logic, structured in the MVC pattern; Microsoft SQL Server for persistent storage; HTML5, CSS3, and Bootstrap for markup and responsive styling; AngularJS for the dashboard single-page-application layer; and AJAX for asynchronous interaction with controller endpoints. The application is hosted on IIS and developed in Microsoft Visual Studio. The SMS gateway is integrated through its RESTful HTTP API using JSON payloads, with credentials held in server-side configuration outside the web root.

The stack was selected for three reasons: its prevalence in Bangladeshi institutional deployments, which localizes maintenance risk; its integrated tooling for data access, authentication, and deployment on Windows Server; and the maturity of its security primitives (built-in request-validation and anti-forgery facilities, Section 6). One honest qualification belongs on the record: AngularJS reached end-of-life in December 2021 and no longer receives security patches [14]; a migration of the presentation layer to a currently

supported front-end framework is included in the future work of Section 9. The server-side stack, which carries all security-critical logic, remains on supported releases.

Development followed the phases of the conventional software development life cycle (Figure 4)—feasibility study, requirement definition, specification, design, program design and coding, testing, and implementation—but executed them iteratively rather than strictly sequentially. As Figure 5 illustrates, the work was organized into successive iterations of planning, requirement analysis, design, building, and testing, each delivering a working increment: the first iteration produced guardian and child registration with record viewing, the second added the schedule engine and reminder dispatch, and later iterations added campaigns, reporting, and the administrative surfaces. This arrangement allowed the schedule engine to be exercised against real data early, before the reporting and campaign features that depend on it were built.

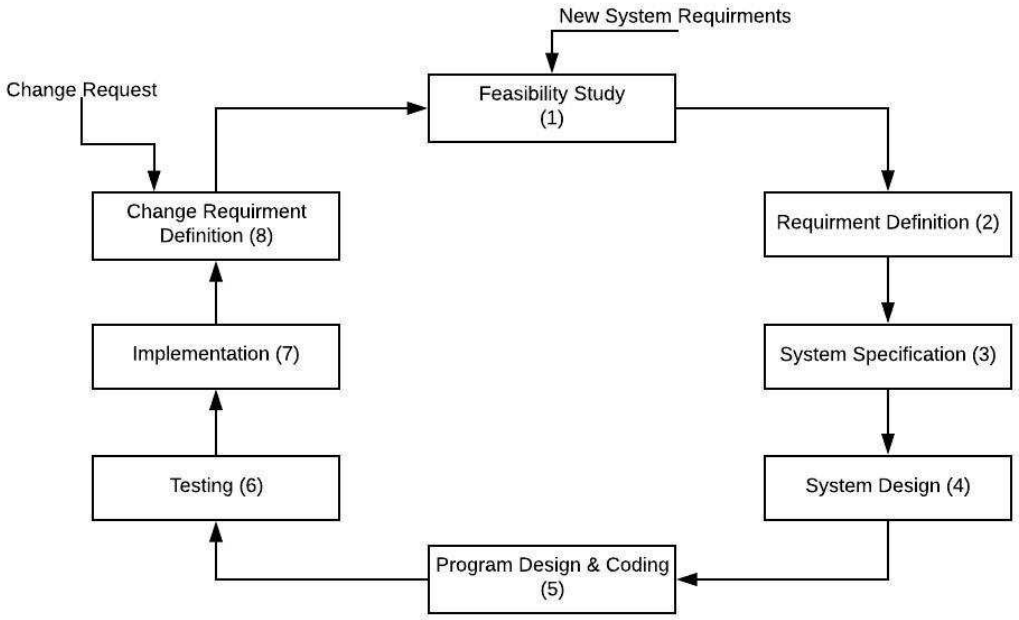


Figure 4: Software development life cycle phases followed in the project.

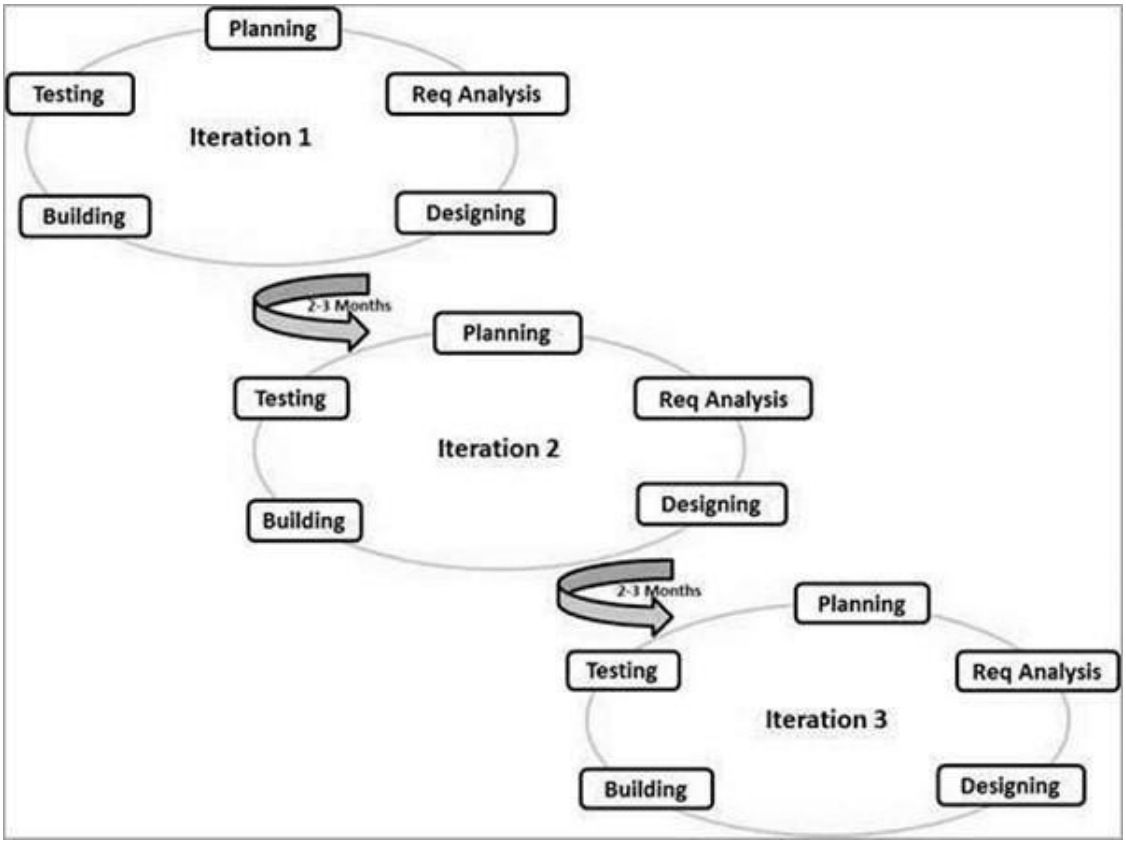


Figure 5: Iterative delivery: each iteration revisits planning, analysis, design, building, and testing.

5.2 Schedule configuration and instantiation

The national EPI schedule configured into schedule_entries at implementation time is shown in Table 2. The dates derive from Bangladesh's adaptation of the WHO generic schedule [3]; fractional IPV at 6 and 14 weeks reflects Bangladesh's early adoption of the fractional dose presentation.

Table 2. Bangladesh EPI schedule as configured in the system (adapted from [3]).

Vaccine	Doses	Scheduled ages
BCG	1	Birth
Pentavalent (DTP-HepB-Hib)	3	6, 10, 14 weeks
OPV	3	6, 10, 14 weeks
PCV	3	6, 10, 14 weeks
Fractional IPV	2	6, 14 weeks
Measles-rubella (MR)	2	9 months, 15 months
Td (women 15–49)	5	+1 month, +6 months, +1 year, +1 year, +1

Vaccine	Doses	Scheduled ages
		year after the first dose
Vitamin A	—	6–59 months (supplementary)

Because the schedule is data, the 2023 introduction of HPV vaccine into the national programme [3] would be absorbed as new rows in vaccines and schedule_entries with no code change—the configurability requirement (FR11) in action.

5.3 Notification pipeline

The notification pipeline is asynchronous by construction. When the scheduler's sweep identifies records whose reminder rows have reached their scheduled time, it generates personalized message text from the template, hands the batch to the SMS adapter, and writes reminders rows with dispatched_at timestamps and initial delivery status. The gateway's delivery-receipt callbacks update delivery_status, distinguishing delivered from failed/undelivered messages so that employees can see undeliverable contacts (wrong number, expired SIM, out of coverage) in their queue rather than assuming delivery. Transient gateway failures retry with exponential backoff before being marked failed. This pipeline runs independently of user traffic, so reminder-day loads do not contend with interactive use.

5.4 Reporting

Reporting covers three audiences: coverage reports (doses administered versus scheduled, by antigen and period) for programme management; defaulter reports (children with overdue records, ordered by days overdue and filterable by area) for employee follow-up; and audit reports drawn from activity_log for administrators. All reports export to CSV for downstream aggregation.

5.5 Implemented user interface

The screens that realize the design are shown in Figures 6–13. Figure 6 shows the public sign-in form through which all three roles authenticate; the same page is the entry point for guardian self-registration. Figures 7 and 8 show the administrator surfaces: the first summarizes the enrolled user population by role and links to user administration, immunization specification, and daily activity monitoring, while the second presents per-antigen enrollment counts and the campaign entry point. Employee-side functionality is illustrated by the employee registration form (Figure 9) and by the reminder composition screen (Figure 10), which sends a free-text reminder to a selected guardian or triggers a queued reminder to all guardians with a dose currently due—the manual counterpart to the scheduler's automatic dispatch. Campaign handling is shown in Figures 11 and 12; a campaign carries a name, a maximum child age, a target city, and a date, and the list view exposes edit, detail, and delete actions. Finally, Figure 13 shows the guardian-facing child registration form, whose date-of-birth field is the single input from which the entire immunization plan and its reminder timeline are derived.

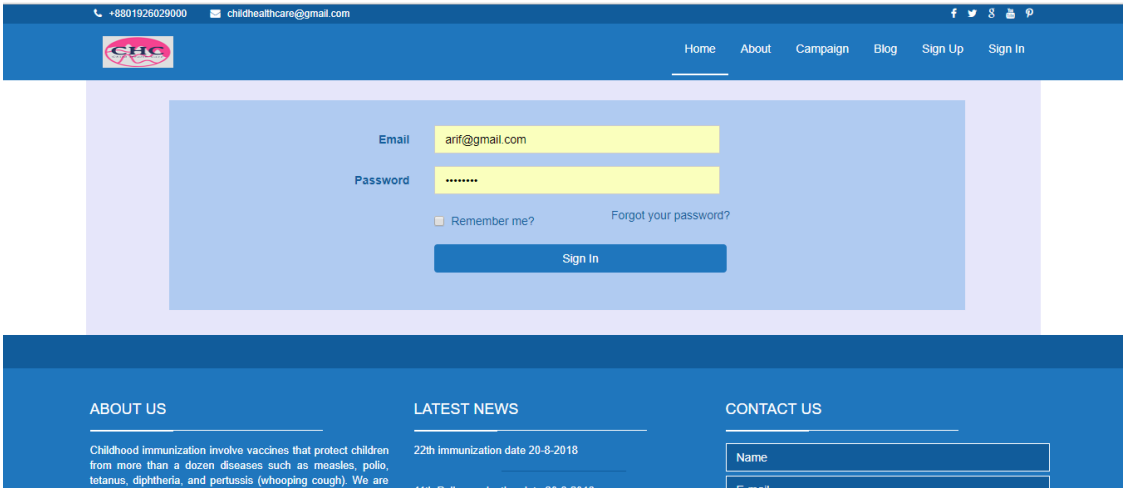


Figure 6: Authentication page, the entry point for administrators, employees, and guardians.

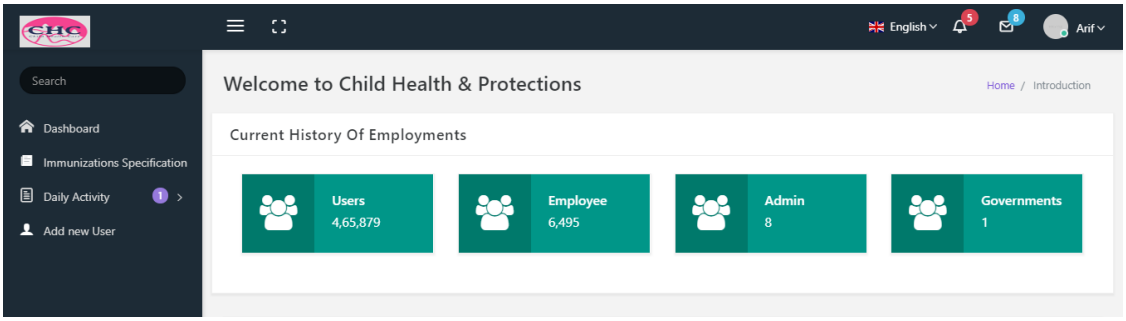


Figure 7: Administrator dashboard summarizing the enrolled population by role.

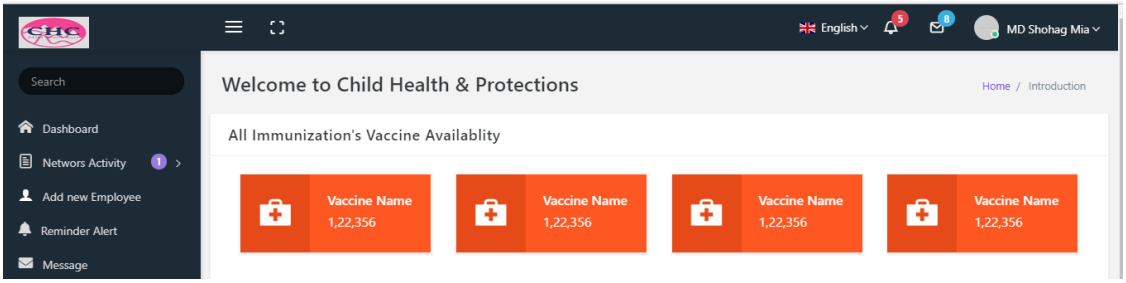


Figure 8: Administrator view of per-antigen enrollment counts and campaign access.

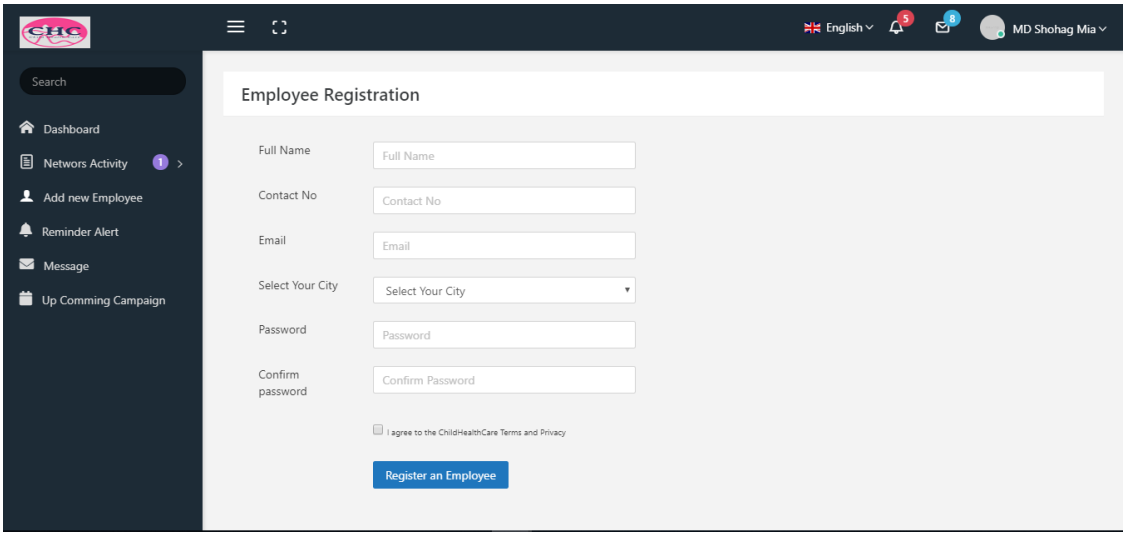


Figure 9: Employee account registration, restricted to administrators.

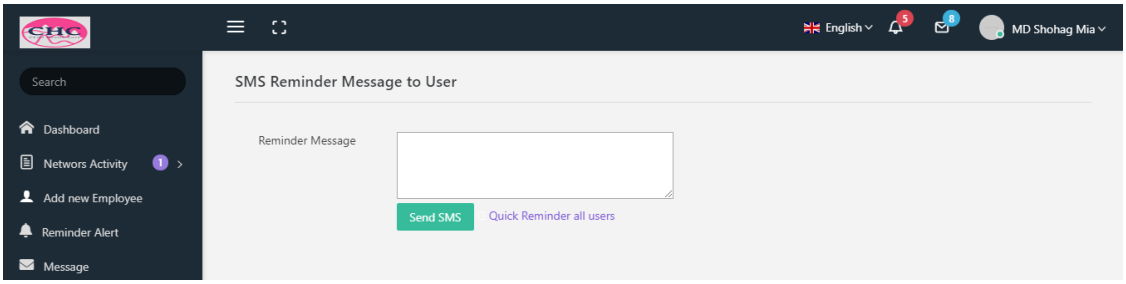


Figure 10: Reminder composition screen used to send an SMS reminder to a guardian or to all guardians with a due dose.

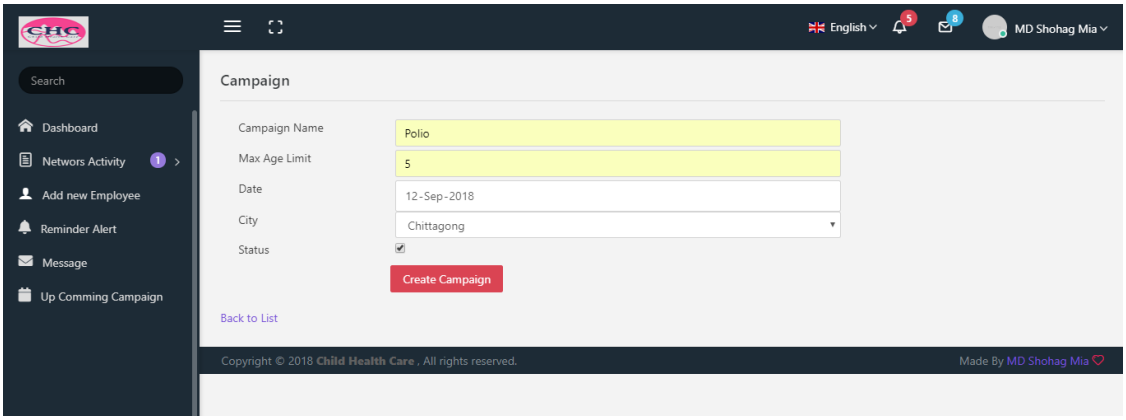


Figure 11: Creating a targeted campaign with a maximum age limit, date, and city.

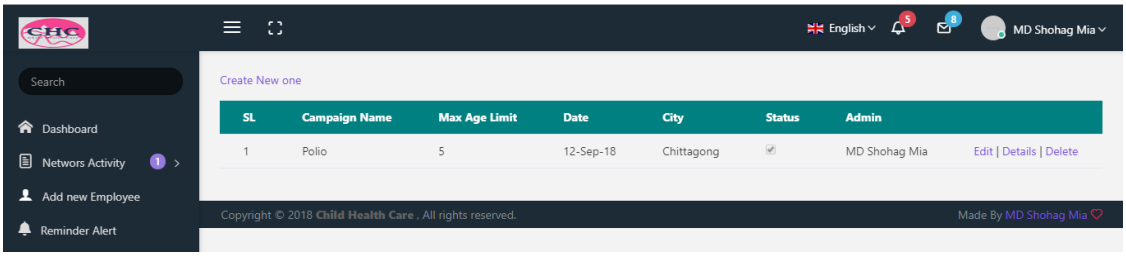


Figure 12: Campaign list view with edit, detail, and delete actions.

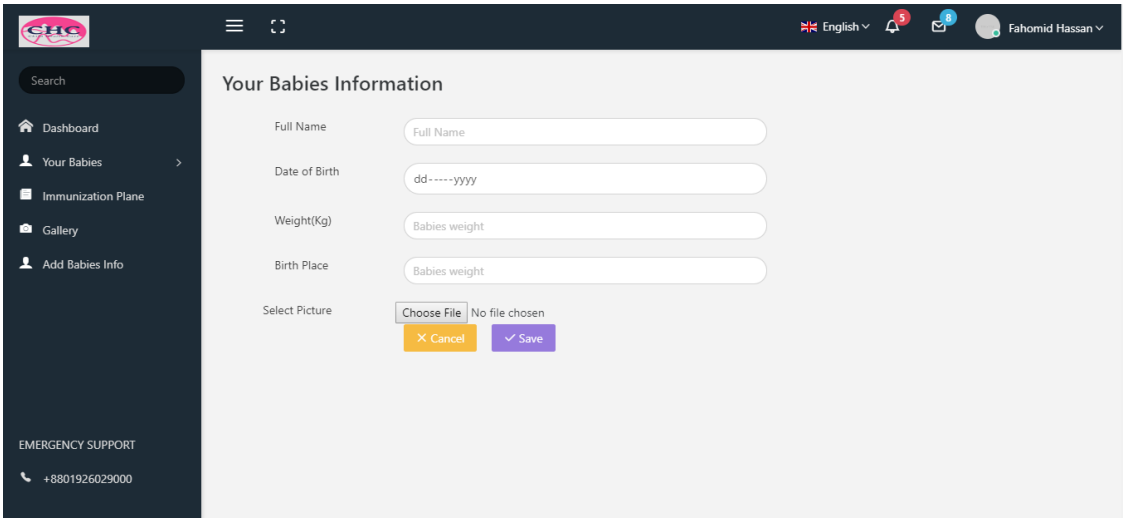


Figure 13: Guardian-facing child registration form; the date of birth anchors all schedule computation.

6. Security and Privacy

A child immunization system is simultaneously a health record system and a system about minors; both facts raise the security bar. The design addresses the threats of the OWASP Top Ten [15] as they apply to this application.

Authentication and password storage. Passwords are stored as salted hashes using a deliberately slow key-derivation function; plaintext passwords are never persisted or logged. Session identifiers are regenerated at login to prevent fixation, and sessions expire after inactivity.

Access control. Role-based access control binds every endpoint to an allowed role set; the guardian data-access path additionally enforces row-level scoping so that a guardian session can read only rows joined to their own guardian_id. Employee scopes bind employees to their administrative area. Administrators alone may modify schedule configuration and user accounts.

Injection. All database access proceeds through parameterized queries; user-supplied values are never concatenated into SQL text. This is the primary defense against SQL injection and is verified by code review as part of testing (Section 7).

Cross-site request forgery. All state-changing POST requests require a per-session anti-forgery token validated server-side, preventing a third-party page from issuing authenticated requests through a guardian's or employee's browser.

Cross-site scripting. Output encoding is applied by default in all templates, with raw-output modes enabled only where content is system-generated rather than user-supplied.

Transport and privacy. The application is served exclusively over HTTPS. Personal data collection follows minimization: the system stores what reminder delivery and clinical record-keeping require—name, date of birth, sex, contact details, area—and nothing more. Notification messages are deliberately light on identifiers: a child's first name and the due date, never the full record, limiting exposure if a shared household phone displays a message to others—a realistic condition in the target population. Guardian consent is obtained at registration, and administrators can delete a guardian's enrollment on request. Activity logging (FR10) provides non-repudiation for data changes.

7. Testing

Testing followed the standard progression from component to whole-system verification. **Unit testing** exercised individual business components in isolation: schedule computation for boundary dates (children born in leap years, vaccines due at week boundaries), template rendering for both languages, and each data-access method against a seeded test database. **Integration testing** verified the composed paths: registration to schedule instantiation to reminder-row creation; dose recording to status transition to reminder suppression; and the SMS adapter against the gateway's sandbox endpoint, including delivery-receipt processing and retry behavior. **System testing** validated end-to-end functional conformance to the requirements of Table 1 through black-box scenarios executed by role, plus white-box inspection of the security-critical paths.

Table 3. Representative functional test cases (black-box).

#	Scenario	Expected result	Outcome
1	Guardian registers a child with date of birth	Full immunization plan instantiated with computed due dates per Table 2	Pass
2	Advance-reminder window reached	SMS dispatched to guardian; reminders row logged with dispatched_at	Pass
3	Dose recorded before due date	Record status → administered; downstream reminders for that dose cancelled	Pass
4	Dose not recorded by due date + 1 day	Recall reminder dispatched; record status → overdue	Pass
5	Administrator edits a	Subsequent instantiations use the	Pass

#	Scenario	Expected result	Outcome
	schedule lead time	new value; no code change required	
6	Employee attempts to access another area's caseload	Access denied by scope check	Pass
7	Guardian attempts to open another guardian's child record URL	Access denied by row-level scoping	Pass
8	Forged POST without anti-forgery token	Request rejected	Pass
9	SQL-metacharacter input in a search field	Treated as data; no query alteration	Pass
10	SMS gateway returns transient failure	Retry with backoff; eventual delivery status recorded	Pass
11	Administrator composes a targeted campaign	Message dispatched to all matching enrolled guardians; per-recipient log entries written	Pass
12	Coverage report requested for a date range and area	Report generated and exports cleanly to CSV	Pass

All functional test cases passed. Two candid caveats bound this result. First, testing establishes functional correctness, not field effectiveness: no randomized or quasi-experimental evaluation of coverage impact was conducted, and the coverage gains documented in Section 2 belong to other interventions, not to a trial of CHCIR. Second, load testing was limited to functional-scale volumes; production-scale dispatch timing for very large cohorts should be re-measured on the target deployment.

8. Discussion and Limitations

The CHCIR system implements, as a configurable general-purpose platform, the intervention pattern whose efficacy is best established in the region: individually targeted, schedule-driven, multi-touch SMS reminders of exactly the kind that produced coverage gains in the mTika evaluation [11] and pooled benefits across LMIC meta-analyses [7], [8], [9]. Three design claims deserve emphasis. First, schedule-as-data means the platform tracks policy rather than freezing it: Bangladesh's programme has introduced antigens repeatedly over recent decades—from pentavalent in 2009 to PCV in 2015, fractional IPV in 2017, and HPV in 2023 [3]—and CHCIR absorbs each as configuration. Second, the reminder-plus-recall structure matches the evidence that cadence matters [7] and that the moment after a missed dose is the highest-yield moment for a cue. Third, the security design (Section 6) takes seriously that the system's records are about children, with row-

level guardian scoping and identifier-light messaging addressing both classical web threats and the shared-phone privacy reality of the target population.

The limitations are substantial and should temper any deployment enthusiasm. **No field evaluation.** The system was verified functionally but never trialed against vaccination outcomes; its expected impact rests on the transferability of cited evidence, and transferability is an assumption, not a result. The honest expectation, given the meta-analytic range of RR 1.09–1.16 [7], [8], [9], is a modest coverage and timeliness improvement, concentrated on timeliness and on children who are already enrolled—reminders cannot reach children who were never registered, which is precisely the zero-dose population identified in recent Bangladeshi survey data [2]. Complementary strategies—outreach registration, birth-notification integration, community health worker follow-up—are required to reach them, and the system is designed to serve such workers rather than replace them. **SMS-channel constraints.** Reminders reach the phone, not necessarily the decision-maker: in many households a shared phone is used by several adults, and paternal grandparents often control vaccination decisions. Message deliverability also depends on third-party gateway reliability. **Legacy front-end.** The AngularJS presentation layer is end-of-life [14]; while all security-critical logic is server-side, migration to a supported framework is necessary before extended production use. **Single-country configuration.** The schedule engine is generic, but the configured schedule, message language, and testing context are Bangladeshi; deployment elsewhere would require local schedule configuration and message localization. **Privacy and data governance.** Storing identifiable children's health data creates a stewardship obligation—backup, retention limits, and breach response—that a prototype must operationalize before real deployments, and national regulatory alignment should be confirmed in each deploying jurisdiction. **Evaluation design.** A cluster-randomized or stepped-wedge trial measuring dose timeliness as the primary endpoint would be the appropriate next evidentiary step; timeliness is where reminder effects are largest [7] and where Bangladesh's valid-coverage gap (81.6% versus ~98% administrative coverage [3], [4]) is most visible.

9. Conclusion and Future Work

This paper presented the CHCIR system, a web-based child health record and immunization reminder platform designed for the Bangladeshi EPI context. The system digitizes individual child records, derives per-child dose due dates from a database-configurable representation of the national schedule, dispatches multi-touch SMS and e-mail reminders with post-due recall escalation, supports campaigns, dashboards, and coverage/defaulter reporting, and secures children's health data through parameterized data access, anti-CSRF tokens, output encoding, hashed credentials, and row-level role scoping. Implemented on the widely supported Microsoft web stack and verified through unit, integration, and system testing with all functional cases passing, the system demonstrates the technical and economic feasibility of schedule-aware individual reminder infrastructure on top of mobile reach that already approaches the entire Bangladeshi population.

The system's chief weakness is the one shared by most engineering contributions: functional verification in place of outcome evaluation. The reminder pattern it implements is strongly evidenced in the literature and locally in Bangladesh, but this particular platform has not itself been trialed. Future work follows four lines. First and most important, a field evaluation—a cluster-randomized or stepped-wedge design with dose timeliness as the primary endpoint—would convert the transferability assumption into evidence. Second, the presentation layer should migrate from end-of-life AngularJS to a supported modern front-end framework, and the deployment should be containerized to simplify installation in low-administration settings. Third, the notification channel should widen beyond text: voice/IVR reminders in Bangla for guardians with limited literacy, following the accessibility direction of mTika's symbol messaging [11], and integration with community health worker mobile tools so that reminders and household follow-up reinforce one another. Fourth, integration with national digital health infrastructure—including birth notification and emerging individual-level community health platforms—would allow CHCIR to function as an interoperable component of the national immunization information landscape rather than a standalone deployment, closing the gap between enrolled children the system can cue and the zero-dose children it must eventually help find.

References

[1] World Health Organization. "Immunization coverage: key facts," WHO, Geneva. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/immunization-coverage

[2] Z. Jannat, H. Das, T. Jannatul, M. W. Ali, N. Alam, C. Morgan, E. Oliveras, G. C. Corrêa, H. W. Reynolds, and M. J. Uddin, "Targeted assessment of prevalence of zero-dose and under-immunised children in Bangladesh," *BMJ Global Health*, vol. 10, no. 12, e018844, 2025. doi: 10.1136/bmjgh-2024-018844

[3] World Health Organization, Regional Office for South-East Asia. *Bangladesh EPI Factsheet 2024*. New Delhi: WHO SEARO, July 2024. [Online]. Available: https://www.who.int/southeastasia/ (Bangladesh EPI fact sheet, immunization schedule 2023, and WHO/UNICEF estimates of national immunization coverage)

[4] UNICEF Bangladesh. "Reaching zero-dose and under-immunized children in 2025: the Bangladesh experience," TechNet-21 community blog, 2025. [Online]. Available: https://www.technet-21.org/en/community/blogs-newsletters/reaching-zero-dose-and-under-immunized-children-in-2025-the-bangladesh-experience

[5] World Health Organization and UNICEF. "Global childhood vaccination coverage holds steady, yet over 14 million infants remain unvaccinated," WHO news release, 2024. [Online]. Available: https://reliefweb.int/report/world/global-childhood-vaccination-coverage-holds-steady-yet-over-14-million-infants-remain-unvaccinated-who-unicef-enar

[6] J. C. Jacobson Vann, R. M. Jacobson, T. Coyne-Beasley, J. K. Asafu-Adjei, and P. G. Szilagyi, “Patient reminder and recall interventions to improve immunization rates,” *Cochrane Database of Systematic Reviews*, no. 1, Art. No. CD003941, 2018. doi: 10.1002/14651858.CD003941.pub2

[7] P. Eze, L. O. Lawani, and Y. Acharya, “Short message service (SMS) reminders for childhood immunisation in low-income and middle-income countries: a systematic review and meta-analysis,” *BMJ Global Health*, vol. 6, no. 7, e005035, 2021. doi: 10.1136/bmjgh-2021-005035

[8] Z. A. Mekonnen, K. A. Gelaye, M. C. Were, K. D. Gashu, and B. C. Tilahun, “Effect of mobile text message reminders on routine childhood vaccination: a systematic review and meta-analysis,” *Systematic Reviews*, vol. 8, art. 154, 2019. doi: 10.1186/s13643-019-1054-0

[9] G. E. Louw, A. S. J. Hohlfeld, R. Kalan, and M. E. Engel, “Mobile phone text message reminders to improve vaccination uptake: a systematic review and meta-analysis,” *Vaccines*, vol. 12, no. 10, art. 1151, 2024. doi: 10.3390/vaccines12101151

[10] A. Oyo-Ita, O. Oduwole, D. Arikpo, E. E. Effa, E. B. Esu, Y. Balakrishna, M. T. Chibuzor, C. M. Oringanje, C. E. Nwachukwu, C. S. Wiysonge, and M. M. Meremikwu, “Interventions for improving coverage of childhood immunisation in low- and middle-income countries,” *Cochrane Database of Systematic Reviews*, no. 12, Art. No. CD008145, 2023. doi: 10.1002/14651858.CD008145.pub4

[11] M. J. Uddin, M. Shamsuzzaman, L. Horng, A. Labrique, L. Vasudevan, K. Zeller, M. Chowdhury, C. P. Larson, D. Bishai, and N. Alam, “Use of mobile phones for improving vaccination coverage among children living in rural hard-to-reach areas and urban streets of Bangladesh,” *Vaccine*, vol. 34, no. 2, pp. 276–283, 2016. doi: 10.1016/j.vaccine.2015.11.024

[12] M. J. Uddin, N. C. Saha, Z. Islam, et al., “Improving low coverage of child immunization in rural hard-to-reach areas of Bangladesh: findings from a project using multiple interventions,” *Vaccine*, vol. 30, no. 2, pp. 168–179, 2012. doi: 10.1016/j.vaccine.2011.11.030 (PMID: 22108489)

[13] Association of Mobile Telecom Operators of Bangladesh (AMTOB), “Industry statistics (mobile subscribers and internet subscribers, citing BTRC),” Dhaka, 2026. [Online]. Available: https://www.amtob.org.bd/home/industrystatics

[14] Google. “Discontinued Long Term Support for AngularJS,” Angular Blog, January 2022. [Online]. Available: https://blog.angular.dev/discontinued-long-term-support-for-angularjs-cc066b82e65a

[15] OWASP Foundation. “OWASP Top Ten,” 2021. [Online]. Available: https://owasp.org/www-project-top-ten/