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Impact & importance of trainings of cold chain technicians on repair and maintenance of electrical cold chain equipment used in cold chain of government health system

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Abstract
The effectiveness of immunization programmes depends on the efficiency of the cold chain system, which ensures that vaccines retain their potency from production to administration. Cold chain equipment such as Walk-in Coolers (WIC), Walk-in Freezers (WIF), Ice-Lined Refrigerators (ILRs), and Deep Freezers (DFs) require regular maintenance to function effectively. Cold Chain Technicians (CCTs) play a vital role in performing timely repair and preventive maintenance. This paper examines the impact of structured technical training programmes on improving the repair efficiency of CCTs, reducing downtime, lowering equipment sickness rates, and strengthening cold chain reliability in government health systems.

Keywords: Universal Immunization Programme (UIP), Sickness Rate, NCCVMRC, cold chain technician, response time, downtime

1. Introduction
Vaccines play a crucial role in protecting children and pregnant women from serious, life-threatening diseases that can be prevented through immunization. They greatly reduce illness and death rates while enhancing overall community health by promoting herd immunity. Among their many benefits, vaccines provide life-saving protection against diseases such as polio. (For e.g. India became Polio free in 2014 due to extensive and continuous vaccination efforts undertaken countrywide. We were able to achieve this feat because of effective vaccines being delivered securely and timely to the last-mile beneficiary. However, these small biological fighters are, in reality, very delicate in nature). Vaccines are temperature-sensitive biological products that must be stored and transported within recommended temperature ranges to maintain efficacy [1]. Any failure in the cold chain can lead to the irreparable loss of vaccine potency, resulting in poor immunization outcomes and wastage of public health resources. Government health systems, particularly in resource-constrained settings, rely on cold chain equipment such as ILRs, DFs, and other vaccine storage units like WIC & WIF to maintain these critical temperature conditions. However, this invaluable precarious cold chain pipeline could become vulnerable due to frequent power fluctuations, lack of preventive maintenance, equipment breakdowns and numerous other factors. Cold chain technicians are the frontline workforce responsible for maintaining these delicate systems. Their skills, knowledge, and availability significantly determine the reliability and resilience of the cold chain system.
The success of essential health programs, such as the Expanded Programme on Immunization (EPI)/ Universal Immunization Programme in the Indian context**,** hinges on the integrity and effectiveness of the vaccine cold chain system [2]. For e.g. India's Universal Immunization Programme aims to ensure that all children and vulnerable populations receive life-saving vaccines and its success is crucially dependent on the quality of the vaccine storage and distribution. Any lapse in this cold chain maintenance especially failures of Ice Lined Refrigerators (ILRs), Deep Freezers (DFs), or other Vaccine Storage (VS) units can lead to ineffective outcomes such as vaccine spoilage, reduced potency, and ultimately, lower immunization coverage.

Therefore, having a reliable, well-maintained cold chain system, supported by trained cold chain technicians, is fundamental to the operational success of EPI/UIP and such other public health initiatives.

A successful cold chain system is built on three essential pillars: (a) well-trained personnel, (b) reliable storage and temperature monitoring, and (c) accurate inventory management of vaccines & cold chain logistics & supply [3]. Well-trained employees, particularly cold chain technicians, ensure timely maintenance, repair, and preventive checks that reduce the risk of equipment failure. Dependable ILRs, DFs, and real-time temperature monitoring systems preserve vaccine potency by maintaining recommended temperature ranges. Additionally, precise inventory management ensures optimal stock levels, reduces wastage, and guarantees that vaccines are available where and when they are needed. Together, these components form the backbone of a resilient cold chain, directly influencing the success of programs like the EPI/ Universal Immunization program (UIP) and other public health initiatives.

2. Materials and Methods

This paper uses a descriptive analytical approach, reviewing national cold chain guidelines, training structures for Cold Chain Technicians, and key maintenance indicators such as Response Time, Downtime, and Sickness Rate. Secondary data from global studies and case examples supplement the findings to demonstrate the effectiveness of structured training programmes.

3. Background

Vaccination is one of the most effective public health interventions used to prevent and, in some cases, eradicate vaccine preventable diseases [4]. It is widely recognized as the most cost-effective strategy for reducing morbidity and mortality from vaccine-preventable diseases, especially in low- and middle-income countries [5]. By strengthening immunization programs, governments can significantly improve child survival rates and reduce the burden on healthcare systems.

The cold chain network is a system designed to store and transport vaccines in a potent state by maintaining them within an acceptable temperature range, typically between +2°C and +8°C, from the manufacturer to the point of administration. This temperature-controlled supply chain is vital for preserving the efficacy of vaccines, especially those sensitive to heat or freezing [6]. In developing countries, a critical challenge faced by the government health cold chain system is the shortage of adequately trained cold chain technicians. Existing technician cohorts are often under skilled and overstretched, with many lacking hands-on experience or formal certification in cold chain equipment repair and maintenance [7].

To address the immediate shortage of skilled cold chain technicians, countries can adopt short-term strategies such as conducting targeted maintenance campaigns that serve a dual purpose: equipment repair and practical, on-the-job training. These campaigns enable technicians to gain hands-on experience directly with Cold Chain Equipment (CCE), under supervision, thereby reinforcing theoretical knowledge with real-world application. This approach not only improves technician competency but also contributes to faster equipment restoration and reduced vaccine storage disruptions [8].

4. Objectives of the paper

- To assess the role of training in enhancing the technical skills of cold chain technicians.
- To ascertain the impact of trained technicians on reducing equipment downtime and improving cold chain reliability, and.
- To understand the broader implications of improved cold chain maintenance on immunization coverage and public health outcomes.

5. Importance of training for cold chain technicians

Training plays a pivotal role in strengthening the operational reliability and sustainability of the vaccine cold chain system [9]. Trainings have been known to positively impact employee performance in the healthcare sector [10, 11]. Skilled Cold Chain Technicians (CCTs) are essential for maintaining critical equipment such as Walk-In Coolers (WIC), Walk-In Freezers (WIF), Ice Lined Refrigerators (ILRs), Deep Freezers (DFs), and Vaccine Storage (VS) units. The key areas where training makes a significant impact include:

5.1 Skill Development: Structured technical training enhances a technician's ability to efficiently troubleshoot, repair, and calibrate various types of cold chain equipment. A well-trained technician is capable of identifying early warning signs of system malfunction such as abnormal temperature fluctuations, compressor issues, or power supply irregularities and can perform timely corrective actions to prevent total equipment failure. This proactive approach minimizes downtime, protects vaccine potency [12], and safeguards public health outcomes.

5.2 Preventive Maintenance: Technicians trained in preventive maintenance can extend the lifespan of equipment, reduce repair frequency, and minimize disruptions in vaccine storage. Training enables technicians to implement preventive maintenance protocols, such as routine checks on thermostats, door seals, condenser coils, and voltage stabilizers. These measures help to extend the operational life of equipment, reduce the frequency of breakdowns, and ensure uninterrupted vaccine storage and distribution, especially in remote and high-demand areas. Preventive maintenance is also more cost-effective in the long run compared to reactive repairs.

5.3 Standardized Protocols: Training ensures uniformity in maintenance procedures across different regions, reducing variability in equipment performance. Uniform training ensures that technicians across different geographic regions follow standardized maintenance and repair protocols, as prescribed by the Ministry of Health and Family Welfare (MoHFW) and supported by WHO guidelines. This reduces inter-regional variability in equipment performance and promotes quality assurance across the immunization cold chain. Standardization also facilitates better documentation and data reporting through platforms like the National Cold Chain Management Information System (NCCMIS**).**

5.4 Capacity building for technological adaptation: With advancements in cold chain technology such as solar-powered ILRs, digital temperature monitoring devices (e.g., eVIN/CoWIN systems), and smart compressors training programs are vital for building a cadre of technologically adept technicians. These professionals are not only able to maintain legacy equipment but are also well-equipped to adapt to emerging technologies and innovations, thereby future-proofing the cold chain system.

6. Types of training programmes for users and cold chain technicians in the healthcare sector [13]

- **Basic training:** Develops the fundamental knowledge about operating and basic maintenance of cold chain equipment, including information specific to common models in use. Such training can be conducted as part of the curriculum.
- **On-the-job training:** Shows Cold chain technicians how to work in health care settings, keep required records, control spare parts and update equipment inventories. It may be provided to technicians by regional or national technical managers,
- **Skill-development training:** Provides training on specialized tasks by providing opportunities to observe, followed by practice. May include short-term training courses at technical training institutes, for example, In India, NCCVMRC is the dedicated National centre for providing such trainings.

7. The Indian Context: National-level institutions for cold chain technician capacity building

In India, two premier institutions have been established to build and strengthen the technical capacity of Cold Chain Technicians (CCTs), specifically for the repair and maintenance of key cold chain equipment such as Walk-In Coolers (WIC), Walk-In Freezers (WIF), Ice Lined Refrigerators (ILRs), Deep Freezers (DFs), and Voltage Stabilizer (VS) units. These institutions are:

7.1 National cold chain & Vaccine Management Resource Centre (NCCVMRC): Located at the National Institute of Health & Family Welfare (NIHFW), New Delhi, NCCVMRC was established in 2013 as the apex technical body under the Ministry of Health & Family Welfare (MoHFW), Government of India. It plays a central role in policy guidance, technical training, and strategic planning for cold chain management nationwide. NCCVMRC provides hands-on, skilled-based trainings to the Cold Chain technicians on repair and maintenance of Ice-Lined Refrigerator (ILR), Deep Freezer (DF), Voltage Stabilizer (VS), Walk-in-Cooler (WIC) and Walk-in-Freezer (WIF).

7.2 National Cold Chain Resource Centre (NCCRC): Situated in **Pune**, NCCRC functions as a key partner institution, focusing on the operational and technical capacity-building of cold chain Technicians. It complements the work of NCCVMRC by conducting hands-on, skill-based training programs.

Together, these centers are instrumental in upskilling Cold Chain Technicians across the states, enabling them to conduct preventive and corrective maintenance independently. Trained technicians significantly contribute to the reduction in equipment downtime, resulting in the restoration of substantial volume of vaccine storage space annually.

This has a direct impact on one of the most critical Key Performance Indicators (KPIs) in cold chain management the Cold Chain Sickness Rate. By ensuring timely repairs and minimizing equipment failures, these training programs help maintain the national target of keeping the sickness rate below 2%, thereby enhancing the reliability and effectiveness of the immunization supply chain.

Another successful example of the impact of training of Cold Chain Technicians was in Ethiopia, where a national maintenance campaign trained 516 mid-level technicians in CCE repair. As a result, the country was able to restore over 100,000 liters of CCE storage capacity [14]. This strategy demonstrates that when on-the-job learning is structured and supported, it can yield measurable improvements in both workforce capability and systems performance. Similar models can be adapted for use in other low-resource settings, particularly in regions where formal training infrastructure is limited or where immediate system strengthening is necessary.

8. Key guidelines for effective cold chain management in India [15]

In India, for repair and maintenance, cold chain technicians have been placed in most of the Districts. It is imperative that these Cold Chain Technicians (CCTs) are adequately skilled, regularly trained, and continuously updated on both existing and emerging technologies to ensure effective vaccine management. The uninterrupted functioning of the cold chain infrastructure crucial for vaccine potency and program success relies on the strict adherence to specific operational protocols. For India, these are defined by the Ministry of Health and Family Welfare (MoHFW), Government of India, in sync with the best international standards such as those of the WHO and UNICEF. Presented below are some of the crucial components of effective cold chain equipment's (CCE) performance monitoring and maintenance.

8.1 Sickness Reporting: Timely and accurate sickness reporting forms the backbone of an effective cold chain maintenance system. A well-functioning reporting mechanism significantly reduces equipment downtime by ensuring rapid response and repair.

Ideally, the system should support direct communication between the service requester (e.g., health facility staff) and the service provider (e.g., cold chain technician), while keeping supervisory and managerial staff informed. This minimizes delays and ensures accountability. Use of digital tools such as the National Cold Chain Management Information System (NCCMIS) is encouraged for real-time tracking and escalation.

8.2 Response Time: Response time is defined as the duration between the notification of a defect in any cold chain equipment and the time when a technician first attends to it.

Example: If an Ice Lined Refrigerator (ILR) becomes non-functional on April 10 and a service request is made the same day, but the technician arrives on April 12, the response time is 2 days.

According to national guidelines, the ideal response time should not exceed 2 days, especially for critical vaccine storage equipment. Delays in response increase the risk of temperature excursions, leading to vaccine wastage and immunization disruption.

8.3 Downtime: Downtime refers to the total period during which any cold chain equipment remains out of service.

Example: If an ILR is reported faulty on April 10 and is restored to working condition on April 20, the downtime is 10 days.

To ensure the operational readiness of equipment:

- Minor repairs should be resolved within 7 days**.**
- Major repairs should not exceed 21 days.

Monitoring of downtime should be a supervisory responsibility, with periodic performance reviews and escalation protocols in place.

8.4 Cold Chain Sickness Rate

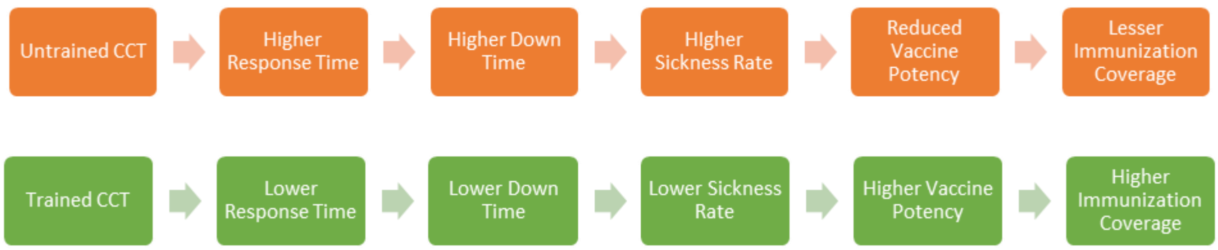
Cold chain sickness rate is a key performance indicator that reflects the proportion of non-functional equipment at any given time. Example: If there are 100 ILRs/Deep Freezers in a district and 7 are currently non-functional (excluding condemned or beyond-repair units), the sickness rate is 7%.
As per Government of India guidelines, the acceptable cold chain sickness rate should be less than 2% at any time. A higher rate indicates systemic issues in equipment maintenance, technician availability, or logistical delays.

$$\text{Cold Chain Sickness Rate} = \frac{\begin{array}{c}\text{Total Number of Nonfunctional but repairable equipment}\\ \text{(Not working + Under repair)}\end{array}}{\begin{array}{c}\text{Total Number of Equipment}\\ \text{(Working + Not working + Under repair + Standby equipment)}\end{array}} \times 100$$

9. Impact of training on cold chain efficiency

The training of Cold Chain Technicians (CCTs) significantly enhances the operational efficiency and resilience of the vaccine cold chain infrastructure. The downstream effects of well-executed training programs contribute directly to public health performance indicators, particularly in immunization delivery. Key areas of impact include:

9.1 Reduced Equipment Downtime: Trained technicians can quickly identify, diagnose, and rectify faults in cold chain equipment, resulting in substantially lower downtime. Early detection of issues such as compressor failures, thermostat malfunctions, or power supply instability enables timely interventions, ensuring that cold chain equipment like ILRs, DFs, and WIC/WIF units remain operational with minimal disruption. This is critical in maintaining continuous vaccine availability, particularly in high-volume or remote health centers.



9.2 Enhanced Vaccine Potency and Safety: Consistent and reliable refrigeration ensures that vaccines are stored within the recommended temperature range (typically +2°C to +8°C for most vaccines). Training ensures that technicians can maintain these conditions accurately, thereby preserving vaccine potency and efficacy. This directly supports the success of national immunization programs, as ineffective or compromised vaccines can lead to reduced immunity coverage and public distrust in health services.

9.3 Improved Monitoring and Documentation: Trained technicians are more likely to adhere to standard protocols for monitoring, logging, and reporting equipment status, repair history, and temperature excursions. Accurate documentation not only aids in preventive maintenance but also enhances transparency and accountability within the cold chain system. Digital tools such as the National Cold Chain Management Information System (NCCMIS) has further improved real-time tracking of equipment, facilitated by trained personnel.

9.4 Cost Savings and Resource Optimization: Investment in technician training leads to long-term cost savings by reducing the frequency of major repairs and the need for premature equipment replacement. Proactive and preventive maintenance minimizes the risk of catastrophic failures, which are typically more expensive and time-consuming to address. This helps optimize the use of limited public health resources, enabling more efficient allocation of funds across the healthcare system.

9.5 Illustrative Example: Trained vs. Untrained Cold Chain Technician: Consider the scenario of a newly recruited or untrained Cold Chain Technician (CCT), who lacks comprehensive knowledge of the National Guidelines on Cold Chain Equipment (CCE) maintenance and is unfamiliar with repair protocols for specialized equipment used in the Universal Immunization Programme (UIP), such as Ice Lined Refrigerators (ILRs), Deep Freezers (DFs), or Voltage Stabilizers (VS).
In such cases, the response time to equipment breakdowns is significantly delayed due to the technician's uncertainty about standard procedures. Additionally, the repair time for both minor and major faults is extended, as the technician may struggle with diagnosis, lack confidence in handling technical issues, or require external support. In contrast, a trained CCT, equipped with both theoretical knowledge and

hands-on skills acquired through structured training programs, is well-versed in:

- Timely response protocols (typically within 48 hours as per national guidelines),
- Standard Operating Procedures (SOPs) for repair and preventive maintenance,
- Use of appropriate tools, and
- Accurate documentation and escalation methods.

As a result, trained technicians not only resolve breakdowns faster but also proactively prevent failures through regular checks and routine maintenance.

This difference is illustrated as:-

- Higher response time and downtime for untrained CCTs.
- Lower downtime and quicker resolution for trained CCTs.

9.6 Public Health Implications: Effective cold chain management is crucial for successful immunization, which not only preserves life but also carries wider public health implications. If the cold chain network is not properly maintained and efficiently implemented, it can have disastrous outcomes for the wider public.

Longer downtimes of CCEs directly threaten vaccine potency due to temperature excursions, which may result in missed immunization sessions, vaccine wastage and ultimately, increased disease incidence or sickness rates in the population. Thus, the presence of trained CCTs is not only a technical necessity but a critical determinant of immunization program success and child health outcomes.

10. Results and Discussion

Training significantly enhances the technical capability of Cold Chain Technicians. Trained technicians demonstrate:

- Faster troubleshooting and fault diagnosis,
- Reduced downtime of ILRs, DFs, and WIC/WIF units,
- Improved preventive maintenance practices,
- Consistent adherence to national guidelines, and
- Enhanced documentation and reporting accuracy.

Comparisons with previous studies indicate that training positively influences equipment performance and cold chain reliability across healthcare settings.

11. Conclusion

Training of cold chain technicians is not merely a technical necessity but a strategic investment in public health infrastructure. The government health system's ability to deliver potent vaccines consistently depends heavily on well-maintained cold chain equipment, which in turn depends on the skill and preparedness of the technicians maintaining them. Structured, regular, and hands-on training programs are essential for building a resilient and responsive cold chain system.

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