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Peer Review

Review of: "Using Immunization Cold Chain Data to Advance Predictive Maintenance: A Narrative Review with Scoping Synthesis"

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The manuscript addresses a highly relevant and emerging topic by exploring how routinely collected immunization cold chain data could support predictive maintenance of cold chain equipment. The paper is well-written, clearly structured, and provides a useful conceptual framework that integrates temperature monitoring, maintenance records, asset management, power reliability, and climate-risk information. The emphasis on phased implementation, starting with simple rule-based alerts before progressing to advanced analytics and artificial intelligence, is practical and well aligned with the realities of immunization programs in low- and middle-income countries.

However, the main limitation of the manuscript is its methodological rigor. Although the study is presented as a *"narrative review with scoping synthesis,"* it does not meet the reporting standards typically expected for a scoping review. The search strategy lacks sufficient detail regarding search dates, study selection procedures, and the number of records identified and included. Furthermore, the review does not critically assess the evidence base, making it difficult to distinguish between findings supported by the literature and recommendations derived from expert opinion. Much of the discussion on predictive maintenance is extrapolated from industrial and engineering sectors rather than from immunization-specific evidence.

Overall, the manuscript makes a valuable contribution by highlighting an important research and implementation agenda for vaccine supply chains. Nevertheless, substantial revisions are needed to strengthen methodological transparency, clarify the review design, and better differentiate evidence-based conclusions from conceptual propositions. Expanding the discussion on model validation,

 doi.org/10.32388/0QJoES

performance metrics, and operational feasibility would further enhance the scientific value of the paper. Therefore, I recommend **Major Revision** before the manuscript can be considered for publication.

Suggested Points for Improving the Manuscript

1. Strengthen the Review Methodology

- Clearly define whether the study is a **Narrative Review** or a **Scoping Review**.
- Provide a detailed and reproducible search strategy.
- Report search dates, databases searched, and search strings used.
- Include the number of records identified, screened, and included.
- Consider adding a PRISMA-ScR flow diagram, even if the review is not fully systematic.

2. Improve Transparency of Evidence Selection

- Clarify inclusion and exclusion criteria in greater detail.
- Describe the study selection and data extraction processes.
- Explain how evidence from immunization settings was distinguished from evidence borrowed from industrial sectors.

3. Expand the Immunization-Specific Evidence Base

- Include more examples from vaccine cold chain and immunization programs.
- Discuss documented cases where temperature monitoring or remote monitoring systems informed maintenance decisions.
- Reduce reliance on evidence extrapolated from Industry 4.0, HVAC, and manufacturing sectors.

4. Enhance the Analytical Discussion

- Identify which variables are likely to be the strongest predictors of cold chain equipment failure.
- Discuss potential predictive targets (e.g., compressor failure, battery degradation, temperature excursion risk).
- Explore how predictive models could be operationalized within national immunization programs.

5. Incorporate Predictive Maintenance Performance Metrics

- Introduce key maintenance indicators such as:
  - Mean Time Between Failures (MTBF)
  - Mean Time to Repair (MTTR)
  - Equipment uptime/downtime
  - Failure rates
- Discuss predictive model performance measures, including:
  - Sensitivity
  - Specificity
  - Precision
  - Recall
  - Area Under the Curve (AUC)

6. Strengthen the Tables

- Explicitly indicate whether each relationship or recommendation is evidence-based or conceptual.
- Add references supporting the key statements presented in Tables 1–3.
- Consider including a table summarizing existing predictive maintenance studies relevant to cold chain systems.

7. Address Implementation Challenges in Greater Depth

- Discuss data governance and ownership issues.
- Address interoperability challenges between asset management systems, eLMIS platforms, and temperature-monitoring systems.
- Examine cybersecurity and data privacy considerations for connected monitoring devices.

8. Expand the Discussion on Artificial Intelligence

- Discuss potential risks of AI implementation, including algorithmic bias and false alarms.
- Describe the requirements for model validation before scaling.
- Emphasize the importance of technician-confirmed outcomes for training and validating predictive models.

9. Improve Discussion of Cost and Feasibility

- Consider the financial implications of predictive maintenance programs.
- Discuss infrastructure requirements, connectivity limitations, and sustainability in low-resource settings.
- Compare predictive maintenance with traditional preventive maintenance from an operational and economic perspective.

10. Strengthen the Limitations Section

- Explicitly acknowledge the limited availability of immunization-specific predictive maintenance studies.
- Clarify that many proposed applications remain theoretical and require field validation.
- Discuss the challenges of generalizing evidence from industrial settings to public health supply chains.

11. Enhance Future Research Directions

- Propose pilot studies to validate predictive maintenance approaches in immunization programs.
- Identify priority datasets and indicators for future predictive modeling.
- Recommend studies evaluating operational impact, cost-effectiveness, and scalability in low- and middle-income countries.

12. Refine the Conclusion

- Clearly distinguish between current evidence and future opportunities.
- Emphasize that predictive maintenance remains a promising but largely unvalidated approach in immunization supply chains.
- Highlight the need for prospective field studies and real-world validation before large-scale implementation.

Declarations

Potential competing interests: No potential competing interests to declare.