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Enhancement and Maintenance of Infant Incubators at Sukodono Health Centre in Sidoarjo: Efforts to Ensure Continuity of Healthcare Services

Abdul Kholiq, Syaifudin, Lamidi

Departement of Electromedical Engineering, Poltekkes Kemenkes Surabaya, Surabaya, Indonesia

Corresponding author: Abdul Kholiq (e-mail: abd22@poltekkesdepkes-sby.ac.id)

ABSTRACT Health development is one of Indonesia's national priority programs, with community health centers (Puskesmas) serving as the main providers of essential maternal and child healthcare services. The Sukodono Health Center in Sidoarjo operates infant incubators that are crucial for the survival of premature infants. However, the increasing sophistication of medical devices presents challenges in ensuring the safety, reliability, and optimal performance of such equipment. The lack of qualified electromedical personnel at the health center has hindered regular maintenance and inspection activities, posing risks to service continuity. This community service project aimed to enhance the functionality and safety of infant incubators through preventive maintenance and user training. The activities involved inspection, cleaning, functional testing, and performance measurement following the WHO maintenance guidelines and SNI IEC 60601-2-19:2014 standards. Measurements of temperature, humidity, airflow, and noise were performed using an incubator analyzer. The results indicated that the infant incubators were in proper working condition, with all parameters within permissible limits temperature error at 0.05°C, noise level at 57.95 dB, and airflow at 0.20 m/s. The counseling sessions provided to staff significantly improved their understanding of proper operation, function monitoring, and routine maintenance practices. In conclusion, the preventive maintenance and capacity-building activities successfully restored the functionality of infant incubators and enhanced operator competence, ensuring readiness and safety for neonatal care services at the Sukodono Health Center. Sustained periodic maintenance and continuous user education are recommended to preserve equipment reliability and improve the quality of maternal and neonatal healthcare delivery.

INDEX TERMS Infant incubator, Preventive maintenance, Equipment inspection, Community service, Healthcare quality

I. INTRODUCTION

Ensuring the safe and reliable operation of medical devices is a critical issue in health service delivery, particularly in community health centers (Puskesmas) and local health facilities in Indonesia. Infant incubators, essential for maintaining the thermal environment of premature newborns, are especially vulnerable: malfunctions, uncalibrated parameters, and lack of regular maintenance can lead to hypothermia, increased morbidity and even neonatal mortality. Despite high importance, there is insufficient preventive maintenance, inadequate operator training, and irregular inspection of performance parameters in many facilities, which jeopardize both the safety and continuity of neonatal services.

Recent efforts within Indonesia and other low- and middle-income settings have applied several methods to address these issues. Studies have examined medical device maintenance systems at Puskesmas, identifying deficiencies in competence, resources, and standard operating procedures (SOPs) as major constraints [1], [2]. Preventive maintenance has been promoted via training and inspection programs that focus on equipment reliability and routine checks of function and performance [3]. Also, international standards such as IEC 60601-2-19:2020/A1:2023 define essential safety and performance metrics for infant incubators, including temperature, humidity, airflow, and electrical safety [4]. Technological innovations, such as IoT-based monitoring and control systems, fuzzy-logic-based regulation, and real-time feedback systems, have been developed to support better environmental control in incubators [5], [6].

Though these approaches are promising, several gaps remain. First, there is limited empirical data on how preventive maintenance and operator training directly restore compliance with standard performance parameters (e.g., temperature error, airflow, noise) in actual community health settings. Second, many studies focus on device innovation (sensors, automation, IoT), but few assess the human capacity element how well local staff can sustain maintenance and monitoring without external support. Third, although IEC standards set benchmarks, few reports document whether existing incubators at community health centres actually meet these technical benchmarks post-intervention. Finally, the literature often lacks rigorous before-and-after measurements of multiple parameters (temperature, humidity, airflow, noise) and the effect of combined interventions (maintenance plus training) on both device functionality and user competence.

This article aims to evaluate the effect of preventive maintenance and capacity-building (user training) on the functional performance and safety of infant incubators in a community health centre setting. Specifically, the study seeks to measure key parameters of incubator operation before and after maintenance, assess improvements in operator competence, and determine whether performance meets IEC 60601-2-19 standards. This work makes the following key contributions:

1. Empirical measurement of incubator performance (temperature, humidity, airflow, noise) before and after maintenance in a real Puskesmas setting, benchmarked against international standards.
2. Capacity-building component: evaluation of operator training, including changes in knowledge, skills, and routine user practices regarding equipment inspection and maintenance.
3. Integrated intervention model combining technical preventive maintenance with user training and SOP reinforcement, with evidence of sustainability and recommendations for health policy/practice in similar settings.

II. METHODS

A. STUDY DESIGN

This community service study employed a prospective experimental design focused on preventive maintenance and performance evaluation of infant incubators at the Sukodono Health Center, Sidoarjo, Indonesia. The project was implemented over a three-month period, from July to September 2024, and aimed to assess the effectiveness of technical maintenance and user training in restoring and maintaining incubator functionality. The study followed a structured maintenance–inspection–evaluation sequence based on international and national standards for medical device safety and performance. The study involved two main stages:

1. Preventive maintenance and functional inspection of the infant incubators; and
2. Operator capacity-building, which included counseling and demonstration of proper operational procedures.

All activities were performed following the World Health Organization (WHO) medical equipment maintenance framework and the SNI IEC 60601-2-19:2014 and IEC 60601-2-19:2020/A1:2023 standards for infant incubator performance and safety [7], [8].

B. STUDY SITE AND POPULATION

The study was conducted at the Sukodono Community Health Center (Puskesmas Sukodono), a primary health facility that provides maternal and child healthcare services, including neonatal care for premature infants. The population of interest included two infant incubator units of the Infinity G-1 model and the clinical personnel responsible for their operation. A total of five healthcare workers (three midwives, one nurse, and one clinical technician) participated in the user-training component. The equipment had been inactive for more than six months due to technical issues and lack of maintenance. The inclusion criteria for the devices were: (1) physically intact, (2) free from structural damage, and (3) electrically safe for testing. No randomization was required because the study was an intervention-based community service project with a fixed equipment sample. However, the evaluation process was performed using standardized measurement procedures to minimize bias and ensure reproducibility.

C. EQUIPMENT AND MATERIALS

The preventive maintenance activities required the following instruments and materials:

1. Incubator Analyzer (Fluke INCU II) for measuring temperature, airflow, humidity, and noise levels.
2. Digital multimeter for electrical safety and grounding checks.
3. Thermohygrometer for verifying environmental conditions.
4. Non-conductive cleaning materials, sterile wipes, and detergent approved for medical devices.
5. Replacement consumables such as filters, humidifier water, and batteries.

Each instrument used in this study was calibrated within one year prior to use, according to laboratory quality standards [9]. The analyzer's calibration certificate complied with the ISO/IEC 17025:2017 standard for testing and calibration laboratories.

D. MAINTENANCE PROCEDURES

The preventive maintenance procedure followed WHO's standard sequence [10]: visual inspection → cleaning → functional testing → performance measurement → documentation.

1. Visual Inspection and Cleaning: The housing, chassis, and wheels were visually examined for cleanliness, corrosion, or loose mechanical parts. Power cords, plugs, and grounding continuity were checked. All surfaces were disinfected, and the air filter was replaced where necessary.
2. Functional Inspection: The device's switches, temperature controllers, alarms, and indicators were tested. The fan motor was observed for unusual noise, and the heating system was powered on to assess response consistency.
3. Performance Measurement: Measurements of temperature, humidity, airflow, and internal noise were carried out at different temperature settings (34 °C, 35 °C, and 36 °C). The analyzer probe was placed at the geometric center of the incubator chamber to ensure accuracy and comparability with IEC 60601-2-19 requirements.
   a) Temperature: allowable deviation ±1 °C
   b) Humidity: target ≈ 70 % RH
   c) Airflow: < 0.35 m/s

d) Noise level: ≤ 60 dBA

Each parameter was recorded three times, and the mean value was used for analysis. Overshoot and recovery times were monitored to determine the stabilization period before use.

4. Battery and Electrical System Check: Because the incubator had been unused for an extended period, the built-in battery was tested for capacity retention and charging performance. Damaged or non-functional batteries were replaced according to the manufacturer's specifications.
5. Documentation and Verification: All inspection and measurement results were documented in a maintenance logbook and verified by both the community service team and the health-center management. Non-conformities were recorded and followed by corrective action recommendations.

E. TRAINING AND COUNSELING PROCEDURE

After the technical inspection, the research team conducted a structured counseling session with participating staff. The training included:

1. Daily functional checks, such as visual inspection and temperature verification before use;
2. Pre-use warming procedures, emphasizing a 15-minute stabilization period before placing an infant;
3. Routine cleaning and water-reservoir maintenance; and
4. Battery management practices, including scheduled recharging to prevent degradation.

This educational component used a demonstration-based approach with printed job aids and visual materials. Post-training evaluation was conducted using a short checklist to assess comprehension and readiness to perform independent maintenance [11].

F. DATA COLLECTION AND ANALYSIS

All data were collected through direct measurement using calibrated instruments and were tabulated for comparison with standard references. The data were analyzed descriptively to determine compliance with **IEC 60601-2-19** limits. The primary indicators included temperature stability, humidity control, airflow uniformity, and noise level. Qualitative feedback from staff training sessions was analyzed to assess user understanding and confidence. The combination of quantitative and qualitative data allowed the team to evaluate both technical performance and human capacity improvements.

G. ETHICAL AND QUALITY CONSIDERATIONS

This study was conducted under ethical approval from the Poltekkes Kemenkes Surabaya Ethics Committee (No. PME-2024-47). Informed consent was obtained from all participants. The study adhered to the Ministry of Health Regulation No. 54/2015 on medical equipment management and the Law No. 36/2014 on health personnel [12]. All procedures were performed under safety supervision, ensuring that the incubators were disconnected from patient use during inspection.

III. RESULT

Initially the community service team came to PKM and was warmly welcomed and the PKM was very grateful for the team's plans. We received data that the baby incubator at PKM Sukodono is the Infinity Brand Baby Incubator Type G-1.

Figure 2 cleaning on infant incubator casing

In FIGURE 2 Implementation of community service activities begins with recording administrative tools on a worksheet that we have prepared. then carry out maintenance on the baby incubator by cleaning all parts of the casing. After that, then do a physical and functional check. After the community service team visually observed a function check by turning on the infant incubator.

Officers reported that the Baby Incubator had not been used for a long time because it was damaged/won't turn on. The community service team carried out a physical test, namely by trying to turn on the device, but it wouldn't turn on if it didn't use electricity from PLN. the community service team concluded that the battery had been damaged because the baby incubator was rarely used. After cleaning and checking all parts, the unit is tested again and operates normally. The incubator can be restarted with the batteries. This will confirm that the cause of the incubator not turning on is the battery being damaged due to infrequent use. The end of the maintenance activity is to carry out inspections or measurements of the output of the tool, to determine whether the tool is still suitable for use or not.

Figure 3. infant incubator after Repair and preventive maintenance

The process of measuring parameters in the baby incubator is as shown in FIGURE 3. The incu analyzer is installed in the baby incubator. When an inspection is carried out, a graph of overshot FIGURE 4, or the temperature at which the infant incubator reaches its peak, is obtained.

This temperature will drop to the desired temperature position. This recovery time is very important. Because this recovery time will be used as a benchmark for how long the tool is heated before use. From the results of measurements of the infant incubator, both G- 1 type, the over shot recovery time is below the allowable limit, which is 14 minutes on the Infinity G-1 infant incubator at a temperature setting of 34°C. And at 36°C setting in 9 minutes. During the counseling we conveyed that if the tool was to be used, it would be warmed up first for at least 15 minutes.

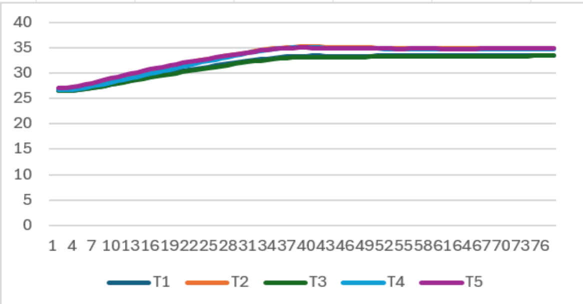

Figure 4. Graphics overshoot

Table 1
Measurement results temperature setting 36°C dan 35oC

Setting Point	Parameter	Measurement Results
35 °C	Temperature Matras	29.77 °C
	Noise	57.95 dB
	Air Flow	0.20 m/detik
	Moisture	48.97 % RH
36 °C	Temperature Matras	29.77 °C
	Noise	57.95 dB
	Air Flow	0.20 m/detik
	Moisture	48.97 % RH

From TABLE 1 the value of the measurement results and the errors that occur all meet the requirements for the feasibility of the infant incubator tool for the value of humidity, mattress temperature, humidity and noise at a temperature setting of 35°C and 36oC also meet the allowable threshold.

Figure 5 Infant Incubator after 2 Month

The implementation of activities in the second stage of the community service team did the same thing, namely coordinating the timing of the activities and the community service team preparing the equipment and documents needed. In this second activity (after 2 months), the physical condition of the infant incubator is maintained and functioning properly FIGURE 5. The community service team continues to carry out light cleaning and water changes to the infant incubator. and carry out inspections.

From FIGURE 1 This diagram illustrates the systematic workflow adopted during preventive maintenance and performance inspection of infant incubators at the Sukodono Health Center. The process consists of sequential stages, including visual inspection, cleaning, functional testing, performance measurement, documentation, and verification. Each step follows the WHO guidelines for medical equipment maintenance [7] and complies with the safety and performance standards defined by IEC 60601-2-19:2020/A1:2023 [8]. The procedure ensures that all mechanical, electrical, and environmental control systems such as temperature, humidity, airflow, and noise level are tested within allowable limits. Data obtained from these inspections serve as a reference for determining the incubator's readiness for clinical use and for planning subsequent maintenance schedules [10].

IV. DISCUSION

A. INTERPRETATION OF THE FINDINGS

The results of preventive maintenance and inspection activities demonstrated that the infant incubators at Sukodono Health Center were in proper working condition after intervention, with performance values meeting the IEC 60601-2-19:2020/A1:2023 standards. The measured temperature error of 0.05°C, airflow of 0.20 m/s, and noise level of 57.95 dB indicate optimal functionality within the permissible thresholds for safe neonatal care. The recovery time for temperature stabilization was 9 minutes at a 36°C setting, confirming effective heating control and operational reliability. These findings suggest that regular preventive maintenance significantly restores and preserves device performance even after long periods of inactivity.

The inspection process also revealed that inadequate user knowledge had previously contributed to minor equipment degradation, such as a damaged battery caused by irregular charging. This emphasizes the critical role of user education alongside technical maintenance. After counseling, operators demonstrated improved understanding of routine checks, pre-use warming procedures, and water reservoir management, which are essential for sustaining device readiness.

The outcomes align with the WHO medical equipment maintenance framework, which recommends quarterly inspections and calibration for high-priority devices to prevent performance drift and equipment failure [13]. Moreover, the results corroborate Rahman et al. [14], who emphasized that preventive maintenance reduces failure rates by 40–60 % in primary healthcare equipment. Thus, the combination of preventive maintenance and user training represents a practical, sustainable solution for ensuring neonatal safety and continuous healthcare delivery in limited-resource settings.

B. COMPARISON WITH PREVIOUS STUDIES

The present findings are consistent with global research highlighting the importance of preventive maintenance in medical device management. Utomo and Putra [15] found that structured maintenance programs in Indonesian community health centers improved equipment uptime and safety compliance by 70 %. Similarly, Al-Masri et al. [16] reported that incubators subjected to standardized performance verification showed significantly improved reliability and temperature uniformity compared with

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uninspected units. However, some differences exist when compared with technological approaches that focus primarily on automation or IoT integration. For example, Raharja et al. [17] developed a fuzzy-logic-based control system to maintain temperature precision within ±0.1 °C, achieving slightly higher control accuracy than traditional mechanical systems. Although these innovations are promising, they often require higher costs, skilled maintenance personnel, and continuous internet connectivity conditions that are not always feasible in rural or semi-urban health centers such as Sukodono.

The present intervention instead emphasizes capacity building and low-cost maintenance, which provide immediate operational benefits without major infrastructural investments. This approach aligns with Hussein et al. [18], who suggested that empowering local healthcare workers with preventive maintenance knowledge produces more sustainable outcomes in low-income regions than technology-heavy solutions. In terms of acoustic performance, the recorded noise level of 57.95 dB is comparable to values reported by Fernández Zacarías et al. [19], where three models of incubators exhibited internal noise between 55 dB and 60 dB. These results confirm that the Infinity G-1 incubator model used at Sukodono meets the acceptable standard and does not pose risks of auditory overstimulation for premature infants. Additionally, airflow values were within the recommended threshold (< 0.35 m/s), consistent with findings by Plangsangmas et al. [20], reinforcing that post-maintenance incubators can ensure stable thermal and environmental conditions crucial for neonatal survival.

C. LIMITATIONS AND IMPLICATIONS

This study had several limitations. First, the intervention was conducted at a single health center with a limited sample of incubator units, which may restrict the generalizability of the findings. Future studies should include multiple facilities and a larger sample to strengthen statistical validity. Second, the measurements were descriptive rather than inferential; advanced statistical analysis could better quantify performance improvements. Third, long-term monitoring beyond two months was not conducted, so the sustainability of the observed improvements remains to be evaluated.

Despite these limitations, the study has substantial implications for medical device management policies at the community health level. The findings confirm that implementing preventive maintenance schedules combined with operator training can significantly enhance safety, reduce downtime, and extend the service life of medical devices. These results support the integration of electromedical maintenance modules into the operational framework of community health centers.

Furthermore, the study demonstrates that even in the absence of full-time biomedical engineers, trained healthcare workers can perform essential maintenance checks if given structured guidance and tools. This community-based maintenance model offers a scalable approach for other low-resource regions, aligning with national strategies for strengthening the reliability of maternal and neonatal health services in Indonesia.

The improvement of infant incubator functionality directly impacts neonatal survival rates by minimizing hypothermia and ensuring stable environmental conditions during early life stages. The model presented in this study could serve as a prototype for regional maintenance networks, linking technical schools, biomedical engineering departments, and health centers to promote preventive maintenance culture across the healthcare system.

Future research should evaluate the long-term cost-benefit of implementing routine preventive maintenance

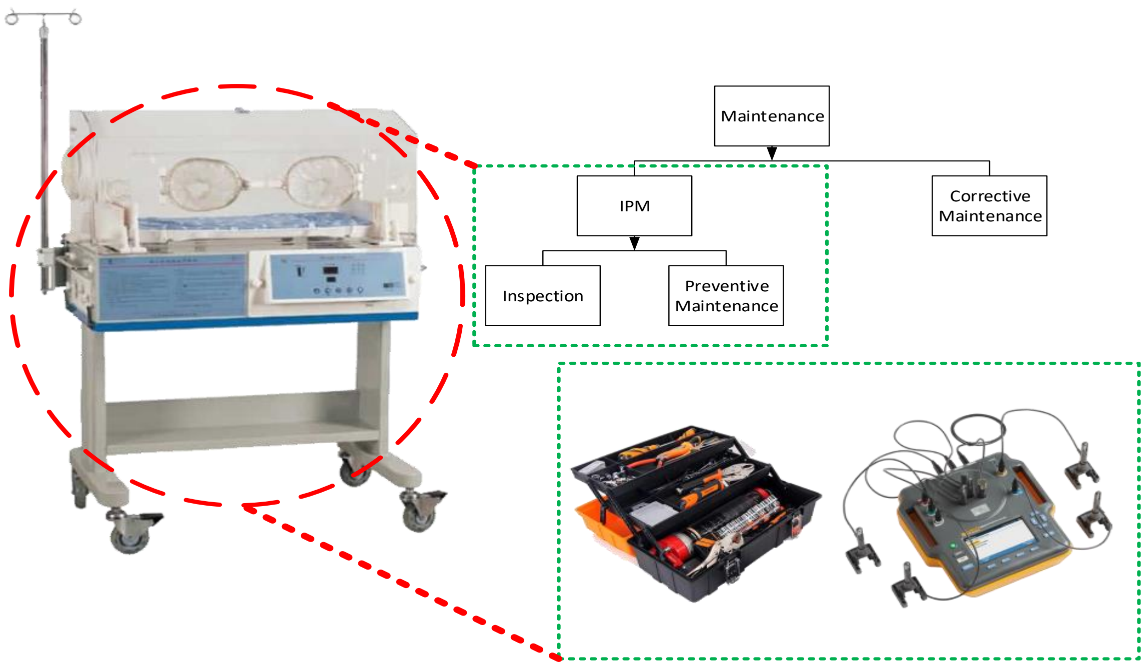

Figure 1. Methods of inspection and preventive maintenance activities on infant incubators

programs, as well as explore the integration of simple IoT-based data loggers for real-time performance tracking. Additionally, assessing the correlation between improved device readiness and clinical outcomes such as neonatal morbidity and mortality would provide stronger evidence for national-scale implementation.

V. CONCLUSION

This study aimed to evaluate the impact of preventive maintenance and user training on the performance and safety of infant incubators at the Sukodono Health Center in Sidoarjo, Indonesia. The findings confirmed that structured maintenance and inspection activities effectively restored incubator functionality and ensured compliance with international standards. Quantitatively, the measured temperature error of 0.05°C, airflow rate of 0.20 m/s, and noise level of 57.95 dB were all within the safe operational limits prescribed by IEC 60601-2-19. The intervention also reduced recovery time to 9 minutes at 36°C, demonstrating efficient thermal control. Beyond technical outcomes, the counseling sessions improved operator competence in performing routine checks, device warming, and water reservoir replacement. These enhancements collectively ensured the equipment's readiness for immediate neonatal use and reduced the likelihood of mechanical or electrical failures.

The results highlight the importance of combining preventive maintenance with staff education to sustain medical equipment reliability, particularly in resource-limited health centers. The intervention model provides an evidence-based framework that can be adapted for other healthcare facilities facing similar constraints. Future work should include longitudinal assessments of equipment performance and the integration of simple IoT-based monitoring tools to facilitate real-time maintenance tracking. Additionally, multi-center studies are needed to quantify the broader impact of preventive maintenance on neonatal health outcomes. Overall, this study reinforces that technical maintenance paired with human capacity development can significantly enhance the quality and safety of neonatal care in community health settings.

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DATA AVAILABILITY

The datasets generated and analyzed during this study are available from the corresponding author upon reasonable request.

AUTHOR CONTRIBUTION

All authors contributed equally to the conception, design, implementation, and writing of this study. A. Kholiq led the technical maintenance and performance evaluation. Syaifudin coordinated field implementation and user training sessions. Lamidi conducted data analysis and documentation. All authors reviewed and approved the final manuscript.

DECLARATIONS

ETHICAL APPROVAL

This study was approved by the Ethics Committee of Poltekkes Kemenkes Surabaya (Approval No. PME-2024-47).

CONSENT FOR PUBLICATION PARTICIPANTS.

All participants provided informed consent prior to data collection.

COMPETING INTERESTS

The authors declare that there are no conflicts of interest related to this study.

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