Received April 23, 2024, accepted November 13 2024, date of publication December 18 2024.

Original Research Article

Assessment and Capital Planning of a Regional Clinical Engineering Department Test Equipment Inventory

Samantha Puin Avila*, Marie-Ange Janvier and Andrew A.M. Ibey

The Clinical Engineering Department, the Children's Hospital of Eastern Ontario (CHEO), Eastern Ontario, Canada.

* Corresponding Author Email: SPuin020@uottawa.ca

ABSTRACT

The Clinical Engineering Department at the Children's Hospital of Eastern Ontario (CHEO) in Eastern Ontario, Canada has 9 distinct regional locations. CHEO's regional program faces a challenge managing a fleet of 345 pieces of test equipment, mainly due to a lack of standardization. Distant regional sites share equipment, making coordination essential. This article presents three unique themes: (1) the introduction of technologist standard kits (*e.g.*, multimeters, electrical safety analyzers, *etc.*) and site-based kits (*e.g.*, ventilator, electrosurgical unit testers, *etc*.); (2) the optimization of kit allocation; and (3) a novel test equipment replacement strategy using *Reliability, Frequency of Use, Life Expectancy, and Usage Classification* criteria. This needs assessment for new equipment, and the replacement of aged equipment will ensure standardized and up-to-date test equipment that will, in turn, minimize equipment-related disruptions and improve technologist productivity.

Keywords—*CMMS, Test equipment, Maintenance, Weighting factor, Reliability, Life expectancy, Usage classification, Frequency of use, Inventory assessment.*

INTRODUCTION

The Children's Hospital of Eastern Ontario (CHEO) is an academic tertiary pediatric hospital in Ottawa, Ontario, Canada. This specialized hospital provides high-quality, standardized, coordinated pediatric health care to approximately 500,000 children and youth annually.[1]

CHEO operates a large regional clinical engineering department with over 50 staff members covering 15,000 km^2. This demands a highly organized team and extensive coordination to keep all the medical equipment up to date. Currently, CHEO oversees a fleet of 345 test equipment devices, valued at approximately CAD 900,000, distributed across nine regional sites, making proper inventory management crucial for ensuring compliance and directly impacting the quality of patient care.[1]

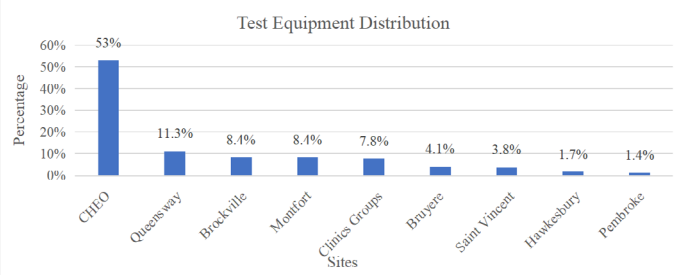

FIGURE 1. Test equipment distribution across regional sites.

Biomedical Engineering Technologists (BMETs) are the primary test equipment users, as they support medical device technology. They serve as clinicians' first point of contact, spending substantial time on clinical floors to provide general device support advice. They adhere to rigorous maintenance schedules for medical devices and document their activities in the Computerized Maintenance Management System (CMMS) E-automate (ECI Software Solutions, TX, USA).[2]

To optimize resources and reduce costs, CHEO uses a hub and spoke model, where smaller hospitals such as Brockville, Pembroke, and Hawkesbury share specialized test equipment and reserve certain tools from CHEO, the main site, for preventive maintenance tasks on devices requiring annual or semi-annual servicing. However, the shared approach introduces challenges for technologists, particularly delayed work order completion in the CMMS due to scheduling and waiting for particular test equipment. An example of a shared device would be the waste anesthetic gas analyzer.

Additionally, borrowing test equipment from other sites increases the challenge, as technologists must specify the maintenance duration on an ad-hoc basis. This practice affects equipment availability and disrupts workflows when devices are not consistently returned to their original site, returned broken, or disappear. It can also reduce the equipment's lifespan due to greater wear and tear and an increased risk of physical damage from handling, transportation, and potential rough treatment.

The use of older test equipment also affects CHEO technologists' confidence in these aged, outdated, and out-of-support devices, leading them to carry backup equipment as a precaution. This lack of reliance complicates their tasks and slows down workflow. In contrast, modern devices provide greater confidence in performance, improved technical support, and regular updates, contributing to smoother operations and timely completion of work.

To address these issues, this paper introduces an inventory assessment system with a scoring criterion as the foundation for developing a strategic replacement plan. A needs analysis was also conducted to evaluate specific equipment requirements, challenges, and preferences for new devices. This combined approach aims to alleviate equipment-related problems, allowing staff to focus more on patient care, ultimately improving productivity and job satisfaction.

METHODOLOGY

This project was developed in four phases:

Data Collection

An inventory assessment system was implemented using Excel (Microsoft Corporation, WA, USA), using a scoring criterion and data sourced from the CMMS. All regional CHEO sites were systematically organized and color-coded to enable easy differentiation (Table 1).

TABLE 1. Eastern Ontario CHEO Sites.

Sites Column A			
M	Montfort	SV	Saint Vincent Hospital
CH	CHEO Biomedical Engineering	P	Pembroke
B	Brockville General Hospital	Q	Queensway Carleton
C	Clinics Groups	BR	Bruyere
H	Hawkesbury		

Data Validation

After extracting CMMS data, a physical inventory was conducted, recording each device's serial number, make, and model. Discrepancies between the physical inventory and CMMS were identified, and equipment was classified into three categories: physically found and recorded in the CMMS, physically not found and in the CMMS, and physically found and not recorded in the CMMS.

A meeting with BMETs and the Clinical Engineering Manager validated the inventory against CMMS records, assessed equipment needs, and reviewed last year's calibration list to ensure accuracy. Standardizing CMMS names and adopting the Emergency Care Research Institute ECRI-recommended nomenclature improved search efficiency, consistency, and categorization, providing clearer access to equipment details in healthcare settings (Table 2).

Data Analysis

A new scoring system was introduced, incorporating four key categories to calculate the capital planning of test equipment: *Frequency of Use*, *Usage Classification*, *Reliability*, *and Life Expectancy*.

Frequency of Use

The *Frequency of Use* definition indicates how often an individual utilizes a specific supply, categorized as daily, weekly, or monthly based on relevance.[3] For medical devices and test equipment, it specifically refers to their usage by healthcare professionals or Biomed Technologists, which should be documented in the CMMS.

To enhance database accuracy, a Microsoft Forms survey was conducted across regional sites to assess the usage frequency of test equipment, categorizing it as regular (daily to weekly), occasional (monthly to bi-monthly), or rare (semi-annual to yearly).

Table 3 summarizes the survey results, classifying equipment based on the highest number of responses, with ties resolved by recording the highest usage level.

Usage Classification

The term Usage Classification refers to categorizing test equipment based on its functionality, risk of use, or compatibility with medical devices. In Canada, medical devices are classified into four categories based on the risk level they possess to health and safety.[4]

- Class I: Lowest risk (*e.g.*, thermometers).
- Class II: Moderate risk (*e.g.*, diagnostic imaging equipment).
- Class III: High risk (*e.g.*, implantable devices).
- Class IV: Highest risk (*e.g.*, pacemakers).

The alignment between Health Canada's system and test equipment usage is determined by evaluating how often test equipment is used with various classes of medical devices. To accurately reflect the risk level of devices with which the test equipment is associated, a survey was conducted with technologists to identify the medical device class most frequently associated with each piece of test equipment.

Equipment used primarily with high-risk devices, such as Class III medical devices, is assigned a higher weight than Priority III equipment. If the device is used equally across different classes, it is classified according to the higher risk category as shown in Table 4.

Reliability

Medical device *Reliability* is the probability that devices will perform their intended function without failure for a specified period.[5] In this context, Test equipment Reliability similarly refers to consistent operation over time, ensuring accurate assessments of medical devices.

TABLE 2. Example of equipment descriptions and ECRI standardized nomenclature.

Equip ID	Description	ECRI	ECRI Device Code	Maker	Model	Serial Number
BM/1007	Test Equip	Testers	11-399	BCGRO	SA-2010S	13381

TABLE 3. Frequency of use categorization method.

Test Equipment Name	Regular Use	Occasional Use	Rare Use	Results
Test Equip Temperature Meter	3	3	0	Regular use
Test Equip Humidity Meter	3	2	1	Regular use

TABLE 4. Usage classification categorization method.

Test Equipment Name	Priority I	Priority II	Priority III	Priority IV	Results
Test Equip Meter Pressure	1	1	3	1	Priority III
Test Equip Humidity Meter	2	2	1	1	Priority II

To evaluate *Reliability*, an equation was developed that inversely relates device age (A) to the frequency of corrective maintenance, using CMMS data. The formula includes a "+1" factor to account for the incoming inspection of the device.

Reliability is calculated using the formula:

- R=Reliability
- A=Age of the device
- M=Number of corrective maintenances

$$R = \frac{A}{M+1}$$

Reliability thresholds were established and points were assigned (Table 5):

TABLE 5. Reliability scale criteria.

Classification	Reliability Score	Points Assigned
$R > 4$	Reliable	1
$4 \leq R \geq 2$	Medium	2
$R < 2$	Unreliable	3

Life Expectancy

The FDA defines *Life Expectancy* broadly as the time a device remains functional with activities such as upgrades, maintenance, and repairs.[6] In contrast, the Biomedical Engineering Advisory Group offers a more concise list of 16 factors that might affect useful life, such as user profile and business risks as well with an extense list of the recommended *Life Expectancy* of medical devices.[7] Despite these guidelines, deciding when to retire or continue using a device remains complex due to the absence of a universal standard for determining device lifespan.

In Ontario, medical equipment management is decentralized, with hospitals making independent decisions.

CHEO, a regional program, evaluates the replacement of medical devices based on long-term organizational goals, technological obsolescence, productivity impact, patient experience, and the adoption of new technologies and best practices.

While these guidelines are designed for medical devices, they can be used as a proxy for test equipment. The criteria for evaluating test equipment lacks detailed literature or guidelines from recognized biomedical and clinical engineering organizations, complicating the management of its lifespan and replacement.

The average *Life Expectancy* data for medical devices from the Biomedical Engineering Advisory Group's recommended list and the CHEO database was utilized to estimate the *Life Expectancy* of test equipment. Since no specific guidelines exist for test equipment, these averages were applied to ensure consistency with the medical devices they support, enabling a practical approach to managing the lifespan of test equipment. As more precise methodologies are developed, opportunities to further refine these estimates will arise.

Weighting Factor

A *Weighting Factor* for each test equipment was developed based on:

- *Reliability* 25%
- *Frequency of Use* 20%
- *Life Expectancy* 35%
- *Usage Classification* 20%

Table 6 is an example of the database of the test equipment. These criteria are grouped according to their importance, incorporating factors such as the age of the equipment, corrective maintenance records, and authorization status from the Clinical Engineering Manager for retirement.

A request for a quotation was made to segment test equipment by price. Devices over $5,000 were classified as major capital, while those under $5,000 were considered minor capital, each following different procurement pathways (Table 6).

Standard Kit

A standard kit was developed, incorporating a literature review and technologist input, to group essential test equipment into three categories: items for each technologist, items for each site, and optional site-specific items. To maintain its relevance, periodic reviews based on database weight and usage are recommended.

(a.) Technologists: Each individual should possess:

- Electrical Safety Analyzer
- Patient Simulator
- Multimeter
- Basic Toolkit

(b.) Each site should be equipped with:

- Oscilloscope
- Pressure Meter
- Temperature Probe/Calibrator
- Vent Tester High Flow (Optional)

(c.) Each site should have if applicable:

- Defibrillator Analyzer
- Gas Flow Analyzer
- ESU Unit (if there is a surgical unit)
- Ultrasound Power Meter

TABLE 6. Weighting factor.

Age	Years	CM	Life Expectancy 35%	Reliability 20%	Frequency of Use 20%	Usage Classification 20%	Price	Weight
2009	14	8	2	3	3	3	$2,300	2.65
2011	12	7	2	3	3	3	$6,000	2.65

RESULTS

Data Analysis

The survey results indicate a high frequency of test equipment use among technologists, with over half of the fleet utilized weekly or monthly: 60.8% used regularly, 29.6% occasionally, and only 9.6% rarely (Table 7).

TABLE 7. CHEO test equipment *Frequency of Use.*

Quantity of Devices	Frequency of Use	%
210	Regular Use	60.8%
102	Occasional Use	29.6%
33	Rare Use	9.6%

Approximately half of the test equipment is centralized at CHEO, while the rest is distributed across eight other sites. Notably, Pembroke Regional Hospital (1.4% of total equipment), Hawkesbury & District General Hospital (1.7%), and Brockville General Hospital Emergency (8.4%) are significantly distant from CHEO, located 151 km away, respectively (see Figure 2 for a map). To mitigate these geographical challenges, it is recommended that each site be equipped with dedicated test equipment to minimize the need for sharing.

To optimize resource distribution, the following equipment relocations are proposed:

- Laser auto magnetic: Relocate to Hawkesbury.
- Defibrillator testers: Allocate to Brockville and Hawkesbury.
- Test Equipment Gauge Force: Assign to Pembroke, Hawkesbury, and Saint Vincent Hospital.
- Temperature modules: Relocate to Pembroke and Hawkesbury.

In terms of Usage Classification, 60.8% of test equipment is primarily associated with high-risk medical devices classified as Priority IV, highlighting the critical importance of maintaining their accuracy. Additionally, 25.2% of the equipment is mainly used with Priority III devices, 10.5% with Priority II devices, and 3.5% with Priority I devices. This classification helps in optimizing resource allocation, ensuring that the most critical equipment receives the necessary attention (Table 8).

TABLE 8. CHEO test equipment *Usage Classification*.

Quantity of Devices	Usage Classification	%
210	Priority IV	60.8%
87	Priority III	25.2%
36	Priority II	10.5%
12	Priority I	3.5%

The Life Expectancy (Table 9) evaluation reveals that 12.2% of the test equipment is over 15 years old, indicating that these devices are nearing the end of their operational life. Furthermore, 30.7% of the equipment falls within the 8 to 15 year range, meaning that more than half of the fleet is approaching the end of its life cycle. In contrast, 57.1% of the test equipment at CHEO is under 8 years old, demonstrating the hospital's proactive efforts in acquiring new equipment over the years.

TABLE 9. CHEO test equipment *Usage Classification*.

Quantity of Devices	Years	%
42	$R > 15$ years old	12.2%
106	$8 < R < 15$ years old	30.7%
197	$R < 8$ years old	57.1%

Table 10 summarizes the *Reliability* of test equipment at CHEO, indicating strong performance consistency. Notably, 76.2% of the devices score at the minimum level on the *Reliability* scale, while only 10.0% of the fleet demonstrates significant functional inconsistency. These results reflect CHEO's strategic focus on acquiring test equipment that supports long-term workflows.

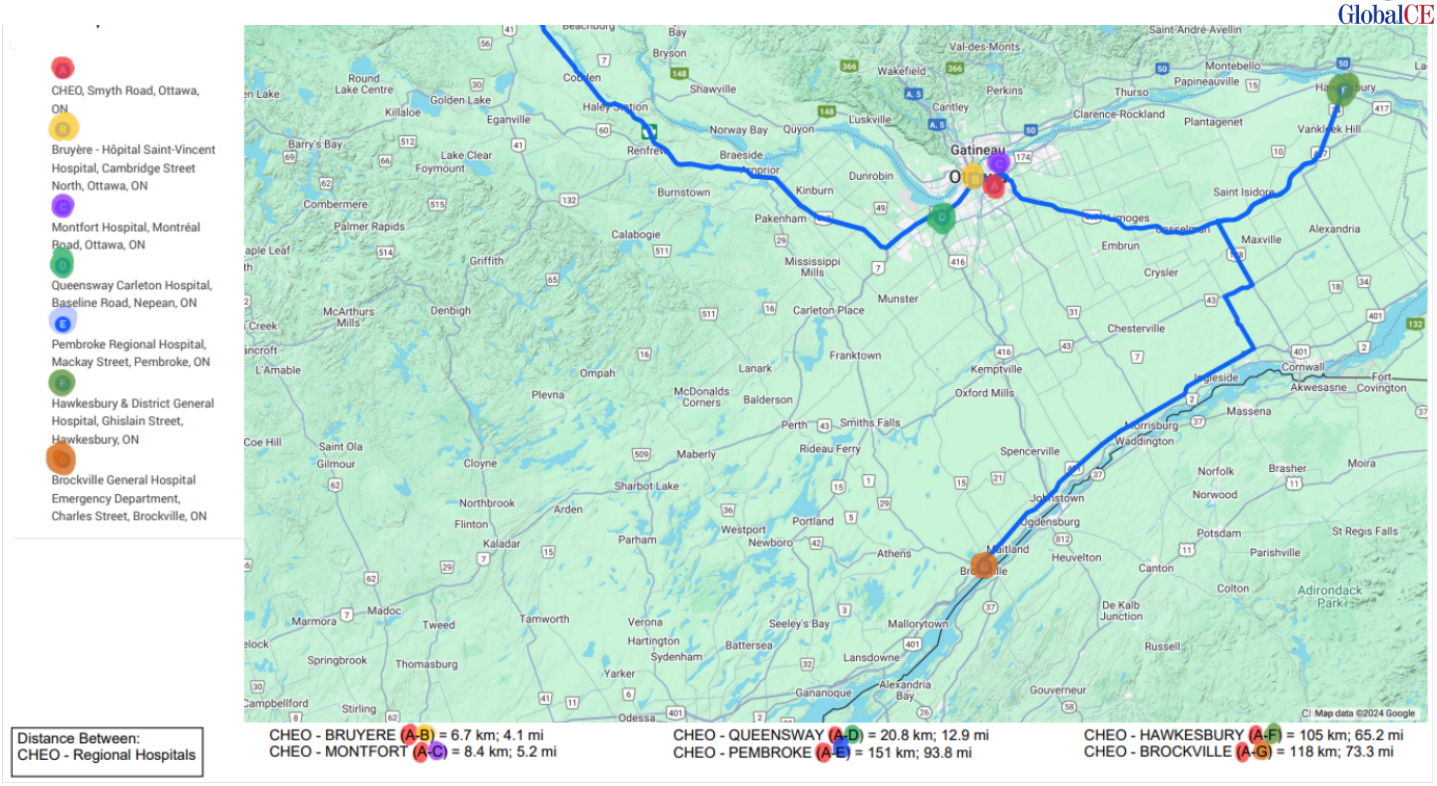

FIGURE 2. CHEO sites distance.

TABLE 10. CHEO test quipment *Reliability*.

Quantity of Devices	Assigned Points	%
37	3	10.8%
45	2	13.0%
263	1	76.2%

The *Weighting Factor* quantitatively reflects the health system's priorities, assigning the highest weight of 35.0% to the age factor, highlighting the critical need for a replacement plan. *Reliability* follows with a weight of 25.0%, showing the importance of acquiring devices that maintain their functions over time to ensure patient safety.

The total cost of the test equipment fleet at CHEO is approximately CAD 863,025, with a calibration cost of $20,602 for 46 pieces of equipment in 2023 showing the hospital's commitment to maintaining high operational efficiency and safety (Tables 11 and 12).

TABLE 11. Test equipment above $5,000 (Capital).

Test Equipment Name	Quantity	Price
Test Equip ESU Unit	6	$6,000
Gas Flow Analyzer	1	$7,700
Test Equip, Test Lung	1	$5,000
Test Equip Defib/Pacemaker	2	$6,500
Test Equip, Simulator Patient Multiparameter	8	$9,000
Test Equip, Ventilator, High Flow	2	$7,700
Total	20	$149,100

TABLE 12. Test equipment under $5,000 (Minor).

Test Equipment Name	Quantity	Price
Test Equip Safety Analyzer	6	$2,300
Test Equip, NIBP	2	$3,200
Test Equip Simulator SpO2	3	$1,000
Multimeter	5	$500
Test Equip Meter, Pressure	1	$2,100
Test Equip Tachometer contact	1	$450
Optical Power/Energy meter	1	$1,250
Test Equip, Simulator, Patient Multiparameter	1	$800
Total	20	$30,300

CONCLUSION

Implementing organized data collection and validation processes improved CHEO's test equipment management. The structured data collection and validation approach has resulted in a fully up-to-date database that reflects the physical inventory, synchronized with the CMMS system. The test equipment is now standardized using the ECRI-recommended nomenclature, ensuring consistency across all sites. Additionally, the color-coded system by site allows for easy filtering and quick location of devices. This organization reduces errors in test equipment location and enhances overall workflow efficiency, minimizing disruptions to hospital operations.

The data on test equipment usage emphasizes the need for a well-distributed inventory to support high-demand devices. With over 60% of the equipment used regularly, there is an increased risk of wear and tear and potential physical damage from frequent handling and transport due to the long distance between the hospitals. Strategically redistributing these frequently used devices will enhance resource management and help ensure their longevity.

The *Life Expectancy* criteria demonstrate the hospital's proactive approach to acquiring new technology, highlighting that over half of the test equipment is regularly used with high-risk medical devices. While *Life Expectancy* accounts for 35% of the replacement decision, the remaining 65% is spread across other critical categories, ensuring a balanced evaluation of equipment prioritization for replacement.

While there are precise methodologies for calculating medical device *Life Expectancy*, limited literature on test equipment highlights the novelty of this article's scoring system for capital planning in the field. This innovative approach provides valuable insights into managing resources and lays the groundwork for future methodologies to enhance evaluation processes. As the field evolves, we expect to integrate factors like wear and tear and calibration, along with more accurate *Reliability* calculations, to improve our assessment and prioritization of test equipment in healthcare settings.

CONFLICTS OF INTEREST

The authors declare they have no competing interests.

ETHICS APPROVAL

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

REFERENCES

1. Children's Hospital of Eastern Ontario (CHEO). Available online: https://www.cheo.on.ca/en/about-us/about-cheo.aspx.
2. Greenwood, K., Janvier, M., Zhang, Y. R., et al. The dividends of an effective clinical technology management program. *J Clin Eng*. 2014;39(1):28–32. https://doi.org/10.1097/JCE.0000000000000010.

3. Griffin, Z.M. Frequency of Meaning Use for Ambiguous and Unambiguous Words. *Behav Res Methods Instrum Comput.*1999;31(3):520–530. https://doi.org/10.3758/bf03200731.
4. Health Canada. Guidance on the Risk-based Classification System for Non-In Vitro Diagnostic Devices (non-IVDDs). Available online: https://www.canada.ca/en/health-canada/services/drugs-health-products/medical-devices/application-information/guidance-documents/guidance-document-guidance-risk-based-classification-system-non-vitro-diagnostic.html.
5. Abd Rahman, N.H., Ibrahim, A.K., Hasikin,K. et al. Critical Device Reliability Assessment in Healthcare Services. *J Healthc Eng.* 2023;2023:3136511. https://doi.org/10.1155/2023/3136511.
6. Food and Drug Administration. Guidance Document: Medical Device Tracking Guidance for Industry and FDA Staff. Available online: https://www.fda.gov/MedicalDevices/DeviceRegulationandGuidance/PostmarketRequirements/MedicalDeviceTracking/default.htm.
7. Biomedical Engineering Advisory Group. Life Span of Medical Devices Guidance Paper. Available online: https://www.academia.edu/10481813/Biomedical_Engineering_Advisory_Group_Guidance_Paper_Life_span_of_Biomedical_Devices_Background.