Building a clinical engineering department: A novel metric-based approach to staffing and workload balancing

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***Abstract*—Appropriate staffing and workload balancing are two of the many challenges that clinical engineering departments encounter daily. Metric based models forecasting PM workloads and analyzing historical CM workloads to predict future needs are one tool that can be used to ensure departments are right sized with appropriate resources. The Ottawa Hospital was used to demonstrate the development and application of these two novel metric-based models for both staffing and workload balancing. The paper also presents a Canada-wide qualitative survey highlighting the consistent challenges in clinical engineering departments across the country.**

Keywords—metric-based staffing model, workload normalization, workload balancing, virtual assets, PM programs

I. INTRODUCTION

It is common for clinical engineering departments (CEDs) to struggle to complete their overall workload given their available resources (i.e. parts budget, labor services, service contracts). In order to combat this strain on department budgets, managers, directors and clinical engineers (CEs) must be strategic to predict resource allocation. In particular, it is important to adequately staff a department based on their predicted workload and then balance that workload between staff appropriately. This applies mainly to biomedical engineering technologists (BMETs) who are responsible for executing most of the department's workload through preventive maintenance (PM), corrective maintenance (CM), installs, investigations, alerts and recalls, educating clinical staff, and other miscellaneous tasks.

Making appropriate strategic resource allocation decisions relies on accurate data collection and detailed data analysis. Unlike a clinical floor which collects data by monitoring patients, CEDs produce their own data by recording their service work on medical equipment related tasks. A capable computerized maintenance management system (CMMS) is a prerequisite and good output data is dependent on the entry of consistent and accurate data through work orders by technologists [5].

Recording good and relevant data, poses several challenges. Technologists must take time out of their tight schedules to document the work they are completing, leaving less time to complete hands-on tasks. This can often result in work orders being recorded inaccurately or with truncated information. Unfortunately, this creates a vicious cycle as the recorded data is often used to advocate for additional department resources.

Further, many value-add tasks (e.g., projects, education, miscellaneous tasks) performed by technologists are difficult to define and document and thereby articulate in business cases. Even with well-defined CMMS data recording standard operating procedures (SOPs) and guidelines, technologists are likely to vary in how they record their work.. These factors can create a paradox between managers who require consistent and accurate time recording, and technologists who already struggle to complete their workload within their working hours.

This paper will explore time tracking practices and predictive resource allocation performed at The Ottawa Hospital (TOH). Practices and challenges from other hospitals across Canada will be compared to TOH using qualitative survey responses. Inconsistent PM compliance and poor tracking of miscellaneous work and project time at TOH and across Canada will be highlighted.

A previous paper focusing on the productivity of BMETs at TOH gave an expected target of 1125 chargeable work hours per BMET per year [1]. This paper will expand on this and propose a predictive workload model for BMETs that considers the time needed to complete PMs, CMs, projects, and miscellaneous work, using this target of 1125 hours per BMET per year. Finally, this paper will propose and define the concept of a novel metric-based workload balancing model.

II. BACKGROUND

A. The Ottawa Hospital Biomedical Engineering Department

The Ottawa Hospital is an adult tertiary academic teaching hospital serving 1.2 million people across Eastern Ontario, Canada. It's three campuses (General, Civic, Riverside) are host to 1,271 patient beds and 21,139 active medical devices. The TOH Biomedical Engineering team consists of 23.4 clinical technologists, 9 diagnostic imaging technologists, 1 clinical engineer, 1 corporate project manager, and 1 CMMS coordinator. This group is supervised by 2 clinical managers who report to the program director.

At TOH, BMETs are either Tech2, Tech3, or Tech4. The Tech2 position is for general duty technologists responsible for lower risk devices, whereas a Tech3 is typically a senior technologist, responsible for higher risk devices. Tech4 positions are responsible for diagnostic imaging equipment and operate separately from the clinical team.

Other biomedical/CEDs will likely have different structures and may include other positions such as administrative assistants, healthcare technology managers, clinical systems engineers, or instrument technicians.

B. Computerized maintenance management systems

The computerized maintenance management system (CMMS) is a powerful tool and a crucial piece of any CED [2]. CMMS software is essential for the daily operation of any maintenance program and has become the key for CEDs to maintain records of inventory and work done by their department [3, 4]. Among many features, CMMSs can produce reports about staff productivity, device histories, right sizing staffing levels and help with resource allocation. The features of a CMMS will vary depending on the specific product used by a hospital [5].

An important factor in a CMMS's reporting ability is how data, such as repair and scheduled maintenance work orders, is entered into the system. It should be noted here that work order entry is a BMET responsibility as part of the job. The ability for a CMMS to produce accurate reports and dashboards for use by managers, CMMS administrators, and clinical engineers depends on technologists inputting data (e.g., time, asset number) accurately, consistently and timely. This may seem obvious, but it has a significant impact on the choices made by department managers.

Accurate data entry produces accurate reports, which in turn enables CEDs to make better informed decisions about staffing, workload balancing, and asset management. Further, many CEDs' ability to secure funding and resources to improve their service is based on technologist entered data. For this reason, it is important that expectations for data entry are clear and technologists' follow SOPs. This paper will explore various in which BMET time is tracked in a CMMS and how it can be used.

C. PM Programs

One of the core functions of a CED is medical device maintenance, both preventive and corrective. Preventive maintenance refers to the periodic scheduled maintenance of devices, performed with the intention to minimize failures and reduce device downtime. The benefits of preventive maintenance include equipment longevity, reduction of repair costs, reduction of patient safety incidents, and minimizing clinical service interruptions [6].

The PM procedure and frequency of maintenance will depend on the type of device as well as it's make and model. Device manufacturers usually recommend PM procedures and frequencies in their support manuals which can be used as a basis for the PM program. There is an ongoing debate in the BME/CE community that manufacturers' recommended PM procedures and frequencies that are too rigorous and too frequent, wasting valuable time and resources on unnecessary maintenance [7]. For this reason, there is growing interest in Alternative Equipment Maintenance (AEM) programs which use CMMS reports like device failure histories to create customized evidence-based PM schedules for devices.

D. Staffing

Determining appropriate staffing levels in CEDs is a puzzle that has yet to be solved definitively. Several studies have attempted to create metric-based predictive staffing models, but each varies in the formula used. One study by Ewing [8] suggests several different metrics including using 1,000 PMs/BMET. Another study from Cruz and Guarin [9] suggests one BMET per 1083.72 devices, and a third by Wang et al. [10] suggests 2.5 BMET/100 operating beds or 1 BMET/600 devices. There is a lack of comprehensive industry research in this area, and those that provide results may oversimplify and/or correct for known data issues. Thus, there is little consensus on which metrics to use and it seems unlikely that any one solution will work for every hospital. This paper will explore ways that hospitals across Canada approach staffing and describe a staffing model that incorporates the time needed to complete the estimated equipment maintenance as well as projects and miscellaneous work.

Balancing the total department workload across staff is another challenge for CEDs and the academic literature is even more sparse on this subject. Simple metrics like "*each BMET is responsible for x number of devices*" ignores the different time requirements for each device (e.g., infusion pump vs. ventilator). Metric-based workload balancing models for CEDs have not been described in the academic literature. This paper will describe a novel workload balancing model that could be used in any CED.

E. Projects

Maintenance and repair tasks aside, projects are the next largest demand on invaluable resources Traditional projects are new installations, or equipment replacement but can also include upgrades to systems and networks like patient monitoring, electronic health records (EHR), digital imaging and communications in medicine (DICOM), and picture archiving and communication systems (PACS).

One of the challenges with predicting time associated with projects is that it isn't as easy to forecast as equipment maintenance. New projects are subject to the release of capital budget, donations, unplanned emergencies, or equipment purchases from associated institutions. Clinical engineering projects may materialize with little warning and produce a large burden. During the COVID-19 pandemic for example, emergency ward expansions and their associated new equipment installations drastically increased workload for nearly all CEDs. Generally, due to the unpredictable timelines and time demands projects are not usually taken into account for staffing levels or workload balance even though they may require a significant amount of time to complete.

Data entry is also an issue that affects projects. BMETs can be involved at various points in a project. They may take part in interdepartmental planning meetings, conversations with vendors, equipment inspections, device installations, and decommissioning old equipment. This is not an exhaustive list and technologists may encounter other miscellaneous tasks. The work performed over a project's timeline can be sporadic, hard to define, and contingent on other departments such as IT, and therefore makes tracking project time accurately challenging. CEDs must have the ability in their CMMS to track projects and need to set clear expectations for documenting time, otherwise a significant amount of BMET may go unaccounted.

III. Methods

A. Data Used

The internal data in this report was retrieved from TOH Biomedical Engineering Department CMMS, Oracle E-business Suite (California, U.S.A.). Data was pulled from the following reports: full asset inventory list of all medical equipment at TOH, PM work order history from 2016 – 2020 (5 full years), CM work order history from 2016 – 2020, and PM forecast from May 2021 – May 2025. Data from 2015 was excluded because TOH began using Oracle E-business Suite (California, U.S.A.) in 2015 and data entry during that year was skewed as the department adjusted to a new system. Data from TOH diagnostic imaging equipment and staff was excluded because of their unique workflow and will not be analyzed herein

B. National Survey

Qualitative data was collected from large hospitals (350+ beds) across Canada using an standardized interview survey. Directors, managers, CMMS administrators, and clinical engineers were asked to voluntarily participate in a one-hour survey regarding department procedures, staffing, and workload normalization. 13 respondents representing 13 different CEDs from British Columbia, Alberta, Manitoba, and Ontario participated in the survey. Survey respondents were each asked 14 open-ended questions and responses were noted. Each participant was asked the same set of questions although participants were encouraged to elaborate on relevant information.

After all surveys were completed, interview transcripts and field notes were individually reviewed and analyzed using qualitative coding and thematic analysis. Belotto [11] provided a thorough description of these techniques to aid students in qualitative data analysis. The surveys yielded more information than could be presented in this paper. Responses were anonymized and any identifiers were removed in hopes that participants would be more candid with their responses to questions.

The survey data serves two purposes for this paper. First, it acts as a benchmark that can be used to compare processes and data from TOH. Second, the survey data forms a snapshot of 13 of Canada's larger CEDs. It reveals some of the trends, challenges, and solutions that are being used at CEDs across the country. Data sharing between hospitals in Canada tends to be limited and increased collaboration could lead to better practices and informed decision making.

Relevant data from the survey will be presented in each of the following sections rather than in its own section.

C. PM Forecasting and Durations

Preventive maintenance work orders accounted for 34% of recorded work order time at TOH during the 2016 – 2020 period. TOH releases forecasted PMs to each technologist's work queue at the beginning of each month and uses "PM durations" to estimate the time needed to complete all scheduled PMs for that month. A "PM duration" is defined as the amount of time needed to complete a PM and all activities associated with the PM (e.g., locating device, performing PM, ordering parts, completing paperwork, etc.). These durations serve several purposes: BMETs are given an estimate of how long their PM task should take, managers are given an estimate of each month's PM workload, and they can be used to assist with annual planning to ensure all months are balanced with slowdown periods in mind. A formal definition of "PM durations" was not found in a literature search, but 6 of the 13 surveyed centers said that they use PM durations to forecast their PM workload.

If forecasted PMs are being used in a staffing model or workload balancing tool, the length of PM durations should be accurate and represent the actual time needed to complete the PM activity. Auditing the many different PM tasks by shadowing technologists would be challenging because of the time needed for such analysis.

To evaluate our PM durations, survey participants were asked to share PM durations or average PM completion time from their own CMMS data for comparison. Participants shared PM durations for models from the 10 device categories that TOH spends the most PM time on:

- Physiologic Monitoring Systems, Acute Care
- Ventilators Intensive Care
- Beds, Electric
- Humidifiers, Heated
- Electrosurgical Units
- Anesthesia Units
- Infusion Pumps, Syringe
- Warming Units, Patient Forced-Air
- Warming Units, Blood/Solution
- Defibrillators External, Semi-Automated

7 of the 13 participants shared data for a few models from each category. Naturally, not every hospital owns the same device models so PM duration comparisons were made for a sample of devices with the most shared data (Table 3)

D. PM Programs

Also of interest was the structure of PM programs at the organizations that were surveyed. The participants were asked if they follow manufacturer recommendations for PM procedure and PM frequency, and if they make any modifications to these recommendations.

Participants were also asked for their PM compliance targets and their actual PM compliance. Some centers divide their PM compliance targets by risk category, setting higher targets for high risk/life-support devices and lower targets for lower risk devices, and other centers set one compliance goal for all devices.

E. Virtual Assets and Projects

Most tasks performed by BMETs can be attributed to a physical asset and charged to its asset number. Some work, however, cannot be attributed to one asset and can be more difficult to track. This work could include repairs performed on accessories without an asset number (blood pressure cuffs, ECG leads, etc.), miscellaneous troubleshooting on clinical floors, supporting clinical staff through conversations, etc.

At TOH, this work is tracked through “virtual assets” – asset numbers that are not tied to a physical asset but can be used to track miscellaneous work performed. Work orders charged to virtual assets appear in CM WO reports. The two most common virtual assets at TOH are:

1) Location codes. Techs can charge time to a unit or location within the hospital. (e.g., “Emergency Department”)
2) Accessory codes. Techs can charge time for work done on accessories used in a specific unit (e.g., “ICU Accessories”)

Although there are virtual assets in the TOH CMMS to track miscellaneous work, there are no SOPs to set a clear expectation for technologists to track all their work to these assets. In reality, this work often takes the form of small sums of time (e.g., 20-minute support conversations with clinical staff) that are not recorded by BMETs but could add up to a substantial workload. BMET’s habits in tracking miscellaneous work varies widely from technologist to technologist. The current CMMS does not have a mobile solution which creates another barrier for capturing this time more easily.

Work performed by BMETs at TOH on projects is also tracked using virtual asset codes. Again, there are asset codes that exist to track this type of work (e.g., “Incoming inspection”, “Install”) but there is little consistency in how different techs record the work performed on projects. This becomes clear when we look at a graph of hours charged to virtual assets over the 2016 – 2020 period.

Fig. 1 shows the level of inconsistency present in tracking time charged to virtual assets and projects. On the upper end, one technologist (outlined in red) charged 2312 hours to virtual assets over 5 years, an average of 462.4 hours per year. In an interview, this technologist stated that they meticulously track and record all the time they spend on projects, including planning meetings, conversations with vendors, incoming inspections, and all work performed in device installations. They also recorded small sums of miscellaneous work.

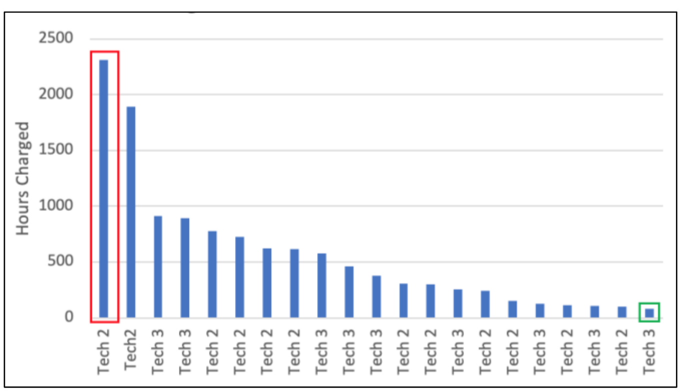

Figure 1: Hours charged to virtual assets from 2016 – 2020

On the lower end, another technologist (outlined in green) charged only 78 hours to virtual assets over 5 years, an average of 15.6 hours per year. This technologist explained that the time spent completing work orders didn’t justify recording the task. They also mentioned that it is not clear how to track projects in the TOH CMMS. Some technologists may simply spend more time working on projects than others, but the extreme variability in the amount of time recorded to virtual assets, along with anecdotal comments made by technologists’ points to a lack of SOPs and expectations for data entry.

Work orders charged to virtual assets accounted for 10.3% of all time charged between 2016 – 2020. This is a substantial portion of time for the department and the actual figure is probably much higher considering the variability in data entry. There is likely work performed on projects and miscellaneous tasks not recorded to work orders.

To understand how other Canadian CEDs compare to TOH, survey participants were asked how they approach tracking time spent on miscellaneous work and projects, and if they’ve been successful in recording this time accurately and consistently.

F. *Metric-Based Workload Normalization*

Clinical engineering assets at TOH are individually assigned to a technologist. The technologist is, in effect, the device owner and is responsible for performing all the work attributed to that device. There is occasionally some collaboration and sharing of workload, but typically a technologist will carry out all the corrective and preventive maintenance required for the devices in their portfolio.

Previously, TOH’s strategy for balancing workload between technologists has been to assign roughly 400 – 500 forecasted PM hours per year per technologist. This was a historical rough estimate based on a senior technologist’s hunch and has not been reassessed for reasonableness or validated within the clinical engineering community. This strategy does attempt to create a workload balance between the available resources, but it ignores the amount of CM a tech will likely encounter based on their specific devices. To improve this approach this study has attempted to predict the annual workload of each technologist based on the specific devices (model/manufacturer) for which they are responsible.

To predict the number of PM hours that a tech might perform in a given year, the PM forecast for 2022 – 2024 and asset inventory database were used. For each model of device, the sum of the PM durations for all forecasted PMs in the 3-year period was taken. This sum was then divided by the number of active devices in the hospital to give the forecasted PM hours per device. Finally, this quotient was further divided by 3 to give the average number of PM hours per device per year. A formula for this calculation follows:

$$\left(\frac{Sum\ of\ PM\ durations\ 2022-2024}{\#\ of\ active\ devices}\right) \div 3\ years$$
$$= Average\ PM\ duration\ per\ device\ per\ year$$

By using a 3-year period, we were able to capture PMs that are only performed every few years (e.g., 2-year PM). Some samples of these calculation are summarized in Table 1.

Table 1: Sample calculations for average PM duration per device per year

Asset Description	Sum of PM Durations 2022 – 2024 (hours)	Count of Devices	Average PM Duration per Device per Year (hours)
Fisher & Paykel MR850 Humidifier	999	333	1.0
Bair Hugger Patient Warming Unit	600	200	1.0
Valleylab FT-10 Electrosurgical Unit	274.5	61	1.5

To predict the number of CM hours that a tech will perform, a similar calculation was done using historical CM WOs from 2016-2020 and the asset inventory database. For each model, the sum of hours charged to all closed and completed WOs was calculated and divided by the number of active devices in the asset inventory. This quotient was divided by 5-years to get the average number of CM hours performed on a device per year.

In the case of CM hours, a separate calculation was made using only the CM WOs from 2020 to get the average number of CM hours performed per device in 2020. For each model of device, the larger of these two calculations (2020 vs average from 2016 – 2020) was used. This was done to account for aging devices. If a device is more prone to failure as it ages and requires more corrective maintenance, we would want to anticipate a greater demand for CMs and use the larger number. A formula for this calculation follows:

$$\text{Larger of: } \left(\frac{Sum\ of\ CM\ hours\ 2016\!-\!2020}{\#\ of\ active\ devices}\right) \div 5\ year\ \textbf{or}\ \left(\frac{Sum\ of\ CM\ hours\ 2020}{\#\ of\ active\ devices}\right) = Average\ CM\ hours\ per\ device\ per\ year$$

These calculations provide an estimated workload in hours per device per year at the level of the device model (Table 2).

With an estimated PM and CM workload per device per year, we can estimate the amount of maintenance a technologist will need to perform in a year given the makeup of the devices in their portfolio. The actual calculated workload balance for each technologist on the clinical team as of June 28, 2021 can be seen in Fig. 2.

Table 2: Sample calculations for total estimated annual workload per device

Asset Description	Average PM hours per device per year	Average CM hours per device per year	Total estimated annual workload per device (hours)
Draeger Isolette 8000 Incubator	2.0	2.9	4.9
Stryker InTouch Critical Care Bed	4.0	0.97	4.97
Philips Respironics V60 Ventilator	2.5	1.26	3.76

In Fig. 2, the RIV1 bar represents all the devices at the Riverside Campus at TOH, an outpatient hospital serviced by technologists on a rotating balance. The BIOTEC bar is a placeholder that represents all devices in the asset inventory database that have not yet been assigned to a technologist (e.g., newly acquired assets, retiring technologists, or shifting technologists' portfolios, etc.). The hatched line at 1125 hours is the ideal number of productive hours per technologist per year [1].

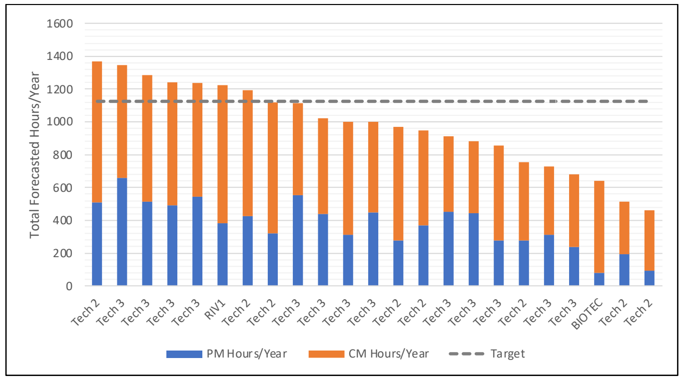

Figure 2: Workload balance between clinical technologists as of June 28, 2021

Clearly, the previous workload balancing practices have resulted in an imbalance across the technologist team (Fig. 2). At one extreme, we have a technologist with an estimated 1369 maintenance hours per year - 244 hours more than their available work hours per year using the previously established 1125 useable work hours/year/BMET [1]. At the other extreme, we have a technologist with an estimated 460 hours per year – 665 hours less than our target workload.

It is important to note, that this study was the first time that this information has been normalized by technologist, yielding a new way of looking at standardized workloads. It also gives managers an opportunity to push back on or debunk the "*I'm already too busy give it to someone else*" response from technologists. The advantage of this metric-based workload normalization method is that it combines the uniqueness of specific devices within their lifecycle to provide individualized workloads for each technologist by using forecasted PM hours/year plus the CM hours/year based on historical CMMS information.

Survey participants were asked how they distribute workload across their technologist team. They were also asked how they determine the overall staff size needed to manage their medical device fleet.

IV. Results and Discussion

A. PM Duration Comparison

A sample of the results of the forecasted PM duration comparison are summarized in Table 3.

The sample of devices shown were chosen because there is a large volume of these devices at TOH and other centres were able to provide data on these devices. With only 7 of 13 participants providing data from their organizations, it was difficult to find common device models that could be compared. These devices and models from their lineage with the same PM procedure (i.e. GE Carescape B450 and B850, Medfusion 3500) account for 13% of all forecasted PM time at TOH.

Table 3: Comparison of TOH PM durations with other organizations

Asset Category	Make/ Model	TOH PM Duration (hours/PM)	Average of other organizations (hours/PM)	% Difference
Monitoring Systems, Acute Care	GE Carescape B650 Patient Monitor	1	1.07	-7%
Ventilators Intensive Care	Vyaire AVEA Critical Care Ventilator	7	3.66	91%
Electrosurgical Units	Covidien ValleyLab ForceTriad ESU	2	2.22	-10%
Anesthesia Units	GE Aisys CS2	3	4.88	-39%
Infusion Pumps, Syringe	Smiths Medical Medfusion 4000	1	1.01	-1%
Warming Units, Patient Forced-Air	Bair Hugger Patient Warming Unit	1	0.74	26%

The sample of devices shown were chosen because there is a large volume of these devices at TOH and other centres were able to provide data on these devices. With only 7 of 13 participants providing data from their organizations, it was difficult to find common device models that could be compared. These devices and models from their lineage with the same PM procedure (i.e. GE Carescape B450 and B850, Medfusion 3500) account for 13% of all forecasted PM time at TOH.

Most of the compared models were relatively similar to other organizations apart from the Vyaire AVEA Critical Care Ventilator. This device has a forecasted PM duration nearly twice as long as other organizations. It may be warranted to shadow an experienced technologist during this PM to understand the reason for this.

Excluding the Vyaire AVEA Critical Care Ventilator, the average percent difference was -6.2% with a standard deviation of 20.8%. PMs may take more or less time depending on the tech performing the activity, as well as the exact PM procedure that an organization follows. There is no industry standard for a reasonable time difference for this comparison, but this comparison seems reasonable enough to give confidence in our forecasted values.

In addition to its use forecasting workload, PM durations have potential for use as a metric to review individual technologist performance. One survey participant stated that they look for anomalies in actual recorded PM times compared to the forecasted PM durations during monthly technologist performance reviews. They explained that this "*could lead to conversations about performance, training, or helping them in some other way*". Using forecasted PM durations in this way assumes that technologists are entering data honestly and accurately. Managers and supervisors would likely need emphasize their expectation for honest data entry and approach this review as a way to support their staff rather than take punitive action. In addition, reviewing monthly data reports would also require a large amount of time for managers or supervisors

B. PM Programs: Procedures, Frequency, Compliance

In general, device manufacturers supply detailed PM procedures and recommended PM schedules to hospitals when they purchase a device. These recommendations, however, are not always followed. Surveyed participants' decisions to follow manufacturer recommended procedures and frequencies can be summarized into three broad categories:

1. Follow manufacturer recommendations exactly
2. Generally follow manufacturer recommendations
3. Committee decides on PM program

The survey results are summarized in Fig. 3.

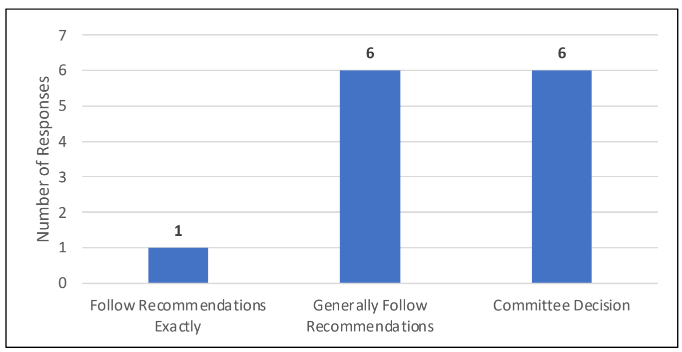

Figure 3: Survey results: setting PM programs to Manufacturer Recommendations

Only 1 surveyed organization claimed to follow manufacturer recommended PM procedures and frequencies exactly. The participant explained that this policy was influenced by their background in medical device industry and their focus on litigation.

6 surveyed participants generally follow manufacturer recommendations. These organizations occasionally made modifications to the procedures and frequencies (e.g., adding/removing steps or altering the frequency) described in device service manuals. Their decisions to make modifications were based on experience with similar devices, or feedback from technologists. For all 6 participants, this is an informal process that does not use structured criteria for decision making. TOH would fall into this category. This is a broad categorization, and it should be noted that the survey didn't investigate specific

details about which modifications being made to PM procedures and frequencies.

Finally, the remaining 6 participants used a formal committee to decide on the PM program for each device. Committee deliberation was focussed on PM frequency, although PM procedures are occasionally modified. Of these 6 organizations, 3 used the "Risked-based biomedical equipment management programme" criteria created by the World Health Organization to decide the PM frequency for new devices [12]. The other 3 organizations used in-house criteria to decide the PM frequency for new devices.

Decisions for PM programs are especially important considering that most CEDs in Canada struggle with their maintenance workload. 12 of the 13 survey participants (92%) admitted that completing their work with their allotted staff and budget was a challenge. This becomes clear when looking at PM compliance rates.

12 of 13 survey participants provided data on PM their target and actual PM compliance. 6 of these 12 organizations separate their PM compliance by high and normal/low risk devices, and the remaining 6 organizations set their PM compliance for all devices regardless of their risk class. Criteria for classifying devices as high or low risk varies from hospital to hospital but high-risk devices tend to be life support equipment like ICU ventilators and normal/low risk devices tend to be common devices such as vital sign monitors or infusion pumps.

PM compliance for the 6 organizations that separate their target and actual PM compliance by high and normal/low risk devices are shown in Fig. 4 and Fig. 5. Data color coding in Fig. 4 and Fig. 5 represent the same organizations.

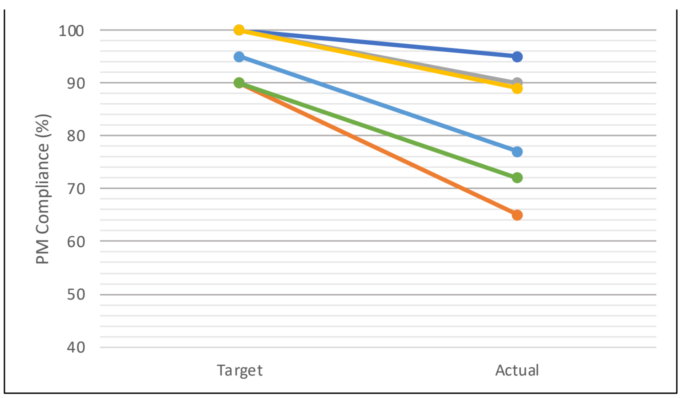

Figure 4: Survey Results: PM compliance for high-risk devices

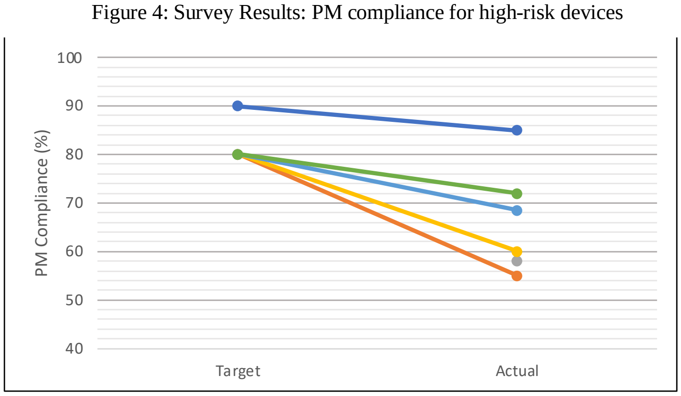

Figure 5: Survey Results: PM compliance for normal risk devices

PM compliance for the 6 organizations that evaluate target and actual PM compliance based on devices of all risk classes are shown in Fig. 6.

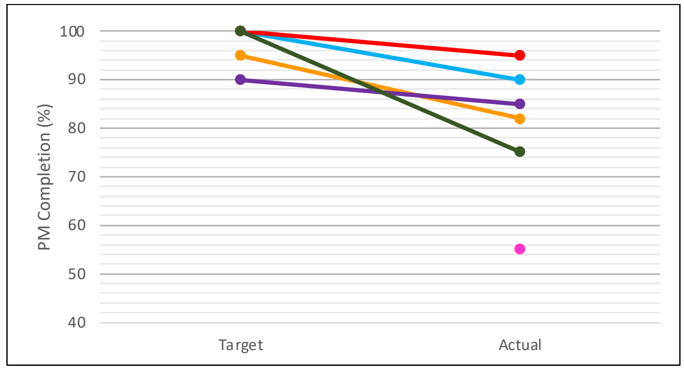

Figure 6: Survey Results PM compliance for all devices

It should be noted that the single data points in the "Actual" column (Fig. 5, 6) represent centres that set their target as "best effort" and do not have a % completion goal. It should also be noted that some organizations gave a range for actual PM compliance instead of a single number. For these centres, the midpoint of the range was graphed (70 – 80% was graphed as 75%).

The data presented herein, demonstrates there is a clear trend for organizations to fall significantly below their targeted PM compliance rates. It appears that high risk devices are being prioritized over other devices, although some centres still fall below 80% compliance for high-risk devices. This trend is consistent across all organizations and illustrates the consensus that participants struggle with the defined and expected workload required for their equipment. This challenge is shared at TOH where our PM compliance target is 100% and our actual PM compliance is 50%.

The strategy of the PM program implemented by an organization had an effect on PM compliance in some cases. In particular, the organization with the highest overall PM compliance, represented by the red data in Fig. 6, uses a committee with stringent in-house criteria to decide if a device needs PM. "*Our committee looks at what we should include in a PM and it's quite aggressive,*" the participant explained. "*We've taken a lot of things off PM from the get-go.*" This type of strategy prioritises higher risk devices while eliminating some lower risk devices all together thereby allowing available resources to focus on real priorities.

In contrast to this strategy, the only organization which stated that they follow manufacturer recommended PM procedures and frequencies exactly, represented by the purple data in Fig. 6, explained that in order to complete their workload, they were "*drowning in overtime*".

There are opinions in academic literature as well as anecdotal opinions from survey participants that manufacturer recommended PM procedures and frequencies are overly cautious and are based on complying with regulatory requirements with a focus on preventing litigation, instead of actual device needs [7,11]. Considering this with the low rate of PM compliance in Canada, perhaps it is time for AEM programs to be considered to eliminate unnecessary and unproductive work that does not increase patient safety concerns and focus on high priority devices [13]. Of course, AEM programs require a significant amount of time and research to create and implement, and BME programs seeking to change to this will require a strong backing from senior leadership to take on the risk to departments, however, an AEM overhaul will provide dividends immediately and into the future [14].

C. Tracking and Miscellaneous Work

When asked how their organizations tracked miscellaneous work that could not be tied to a physical asset, survey responses fell into two categories:

1) Track miscellaneous work
2) Do not track miscellaneous work

The results are presented in Fig. 7.

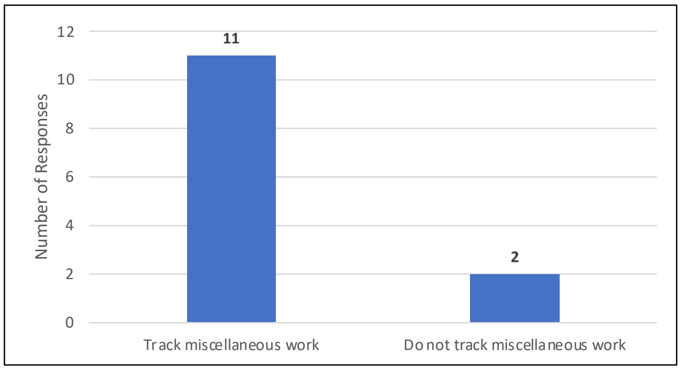

Fig. 7: Survey results for tracking miscellaneous work

Although the exact term "virtual assets" was not used by all organizations, those who tracked miscellaneous work used a system like TOH's virtual assets (i.e., miscellaneous work can be charged to codes for locations, accessories, etc.).

11 of the 13 organizations that attempt to track miscellaneous work also said they were inconsistently tracking their time. Like TOH, they struggle with consistent data entry and think that they are not capturing all their time. This is likely due to the nature of miscellaneous work performed by technologists. These tasks are varied, hard to define, and wouldn't be easily captured by standard workflows let alone logging the time taken for the tasks in a traditional PC-based CMMS. Even with guidelines from management and clear expectations for data entry, technologists are likely to vary in how they record this time.

2 of the 13 surveyed organizations do not track any miscellaneous time. These organizations felt that recording small amounts of time to work orders does not justify the time required to complete the work order.

D. Tracking Project Time

Survey responses regarding how organizations track project fell into 3 categories:

1) Project time tracked well
2) Project time tracked inconsistently
3) Project time not tracked

The responses are presented in Fig. 8.

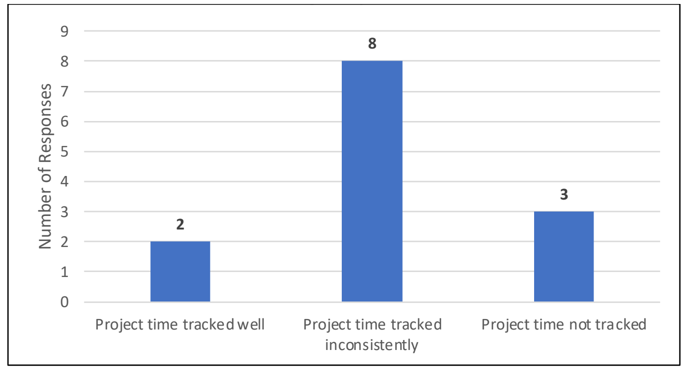

Fig. 8: Survey results for tracking project time

Only 2 of 13 organizations felt that they tracked project time well. Both participants attributed this to the functionality of their CMMS. One organization tracks project time in a separate module of their CMMS designed specifically for projects. The other organization shares a CMMS with their Capital Planning department giving them the ability to charge time directly to a capital project code. This is a great example of how a well-equipped CMMS can help with data entry and analysis.

Most of the survey participants did not think that they track project time well. 8 of 13 organizations attempt to track project time but know that it is not done consistently. TOH would fit into this category. These organizations use virtual assets (or a similar system under a different name) to track their project time. Like miscellaneous work, technologists working on projects perform tasks that are not always easy to define and may also be tedious to enter into a CMMS. These organizations also did not provide a project-based work order setup by the clinical engineer or project manager to allow techs to charge time. With clear expectations for data entry and a CMMS with capable features, however, it does seem possible to record this time accurately.

Finally, 3 of the 13 organizations do not track time spent on projects at all. For these 3 organizations, along with the 8 that track project time inconsistently, there is likely a substantial amount of work that is not being recorded.

Tracking project time is critical, especially with the recent COVID-19 pandemic where the urgency of projects, upgrades, and installations have flooded CEDs across the country, pulling resources from important work to urgent needs. In a data driven world, the CMMS is the only place to systematically document and interpret the happenings of the CED. Data from CMMS reports for project related work could be used in business cases to secure funding, making it even more important for technologists to capture this time, and organizations to simplify data capture methods and to clarify data entry expectations.

E. Metric-Based Workload Balancing at TOH

As described, the following novel workload normalization tool can be achieved by using an estimate of total PM and CM hours per year needed for a technologist to maintain their device portfolio. Since developing an estimated PM and CM workload per device per year, some effort has been made to redistribute workload among the clinical technologist team. Fig. 9 shows the workload balance as of December 2, 2021.

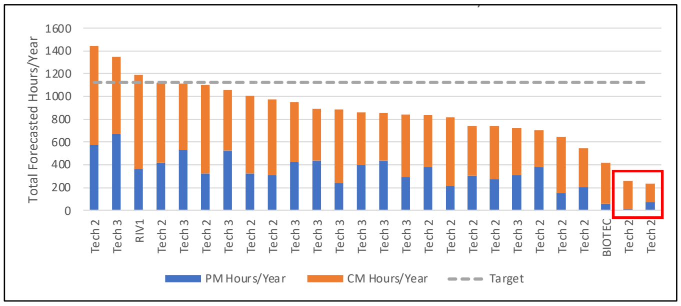

Figure 9: Workload balance between clinical technologists as of December 2, 2021

Imbalances still exist but progress has been made in normalizing workload. Please note that new technologists were added to the clinical team since June 28th and have not yet been assigned a full portfolio of devices, giving them a seemingly small workload (outlined in red).

A literature review did not yield any articles describing metric-based workload balancing for BMETs, but some of the survey participants have used similar strategies in their departments. The survey results regarding workload balancing strategies are presented in Fig. 10.

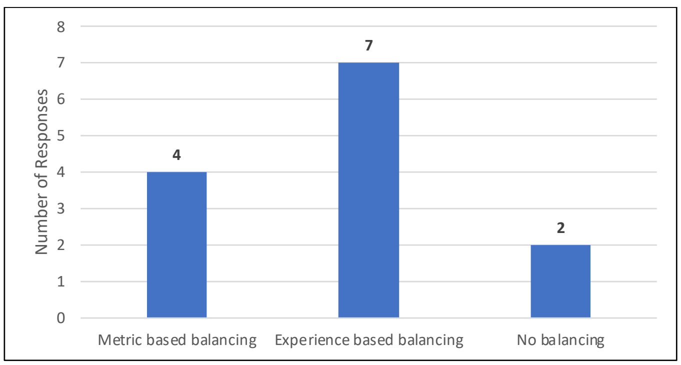

Figure 10: Survey results for workload balancing strategies

Only 4 of the 13 surveyed organizations use metrics to balance workload among technologists. 3 of these organizations use a similar technique described in this paper, estimating annual PM and CM hours based on devices assigned to technologists. The remaining 1 organization uses a formula that considers three factors in workload balancing:

1) Number of hours charged to work orders for assigned devices
2) Total number of assigned devices
3) Total value of assigned devices

These three factors are used as inputs for a formula that produces an output representing workload level. Further details for this formula were not collected and remained out of scope for this paper.

7 surveyed organizations balance workload among technologists based on their professional experience. These organizations do not use a formal metric to distribute devices between techs and teams. One participant described their strategy as, "*more art than science*".

The last 2 organizations do not assign devices to individual technologists or teams, and thus do not need to balance workload. These were smaller clinical engineering teams that relied on technologists taking on PMs and CMs whenever they were available.

Metric-based workload balancing is one tool that can be used for normalizing workload across a team to provide a manager the following benefits: "fairness" distributing workload, retirements/new hires, portfolio shifts for growth opportunities, determine who to assign a new influx of equipment, etc. However, it may not always be the best strategy to rely solely on this model. Different technologists will likely have unique strengths, weaknesses, and abilities that should be considered. Using a technique like the one described in this paper should also be incorporated with professional experience and personal knowledge of team members to achieve an optimal workload balance.

F. Staffing

Using estimated annual PM and CM workloads may also have application as a simple model for staffing. Using a complete asset inventory and expected PM and CM requirements for all device models, we can estimate the amount of work hours needed to maintain a hospital's entire portfolio of clinical medical devices. Further, we can estimate the amount of time needed to complete miscellaneous work and projects using time recorded to virtual assets. Earlier in this paper, this number was calculated and assumed to be 10.3% of total PM and CM time, although this is likely a conservative estimate. The true number may be closer to 20% of total PM and CM time.

An example of a total workload calculation is presented in Table 4. Total PM and CM workload was calculated from all active clinical devices (18,573 devices) included on the December 2021 Asset Extract.

Table 4: Calculation for total annual estimated time required to maintain TOH devices

Activity	Annual Estimated Time Required (hours)
PM for All Devices	8,689.7
CM for All Devices	13,749.8
Miscellaneous and Projects	22,439.5*10.3% = 2,311.3
Total	24,750.8

We have assumed a 70% productivity factor per tech per year, which has been previously described as 1125 hours of 'chargeable' annual work, which is equal to 1 FTE [1]. This assumption can be used to calculate the number of staff to complete the annual total of predetermined work at The Ottawa Hospital. The calculation can be performed as follows:

(24,750.8 hours/year) / (1125 hours/FTE) = 22.0 FTE

Using this model, TOH would need roughly 22 FTE to complete the work required for their portfolio of devices. If a more realistic factor for project time is used, say 20% of total maintenance time, the total annual estimated time would be

26,927.4 hours, calling for 23.9 FTE. This gives a range for the estimated BMET staff needed of 22 – 23.9 FTE.

TOH currently has 23.4 FTE responsible for clinical equipment. According to this model, TOH is roughly right sized for BMET staff, falling within the 22 – 23.9 FTE range. This conflicts with TOH's struggle to complete PMs, at 50% PM compliance but could be in part due to the low "Miscellaneous and Projects" time estimate.

This model relies on having PM and CM data for every device in an asset inventory. The best estimate for new models would likely be similar to models already owned by a CED. This model also assumes that the amount of time spent on projects and miscellaneous work will be similar to previous years, which may not be the case. For instance, the amount of time spent on projects in 2020 was likely much greater than in 2019 due to the COVID-19 pandemic. Future years are also dependent on capital priorities and medical equipment fleet replacement strategies.

It is also important to consider that this model is only as accurate as the data entered by technologists. Forecasted CM hours and virtual asset hours are estimated using historical data recorded to work orders. This model is iterative, in that accurate daily work entry by a technologist in the CMMS for all types of work, will result in better CM historical work and Project/Misc. time estimates. The model will get more accurate over time. Education of this model with technologists to understand why accurate data entry is important and have a clear idea of what managers and supervisors expect of them will help keep sight on the ultimate goal to ensure adequate resources are in the department and optimize the workload balance amongst the resources available. Ultimately, managers, clinical engineers, technologists, and all clinical engineering staff are striving for the same goals and should work and communicate as a team.

Though many of the survey participants were interested in metric-based staffing, departments are not staffed on proposed models but instead by the level of funding allocated to them by hospital administration and leadership. Although CEDs in Canada may not be able to independently decide on their staffing levels, they may find this model to be persuasive in business cases made to directors and VPs to advocate for appropriate resources.

V. Recommendations

A few recommendations can be made for the TOH Biomedical Engineering Department:

1. Auditing PM durations: While most PM durations compared in section 4.1 were fairly consistent with other organizations, the Vyaire AVEA ventilator was considerably longer. It could be helpful to shadow a technologist and understand why this task is taking so long. Other PM durations could be audited using actual PM data recorded to work orders.

2. Considering other PM program structures: PM compliance remains an ongoing challenge at TOH. Adopting an AEM strategy or risk-based PM program could reduce unnecessary workload without compromising patient safety. This has never been done at TOH and could provide tremendous value for the effort. The WHO tool could be used, or in-house criteria could be developed [12].

3. Emphasize accurate data entry: Analysis of work order data revealed inconsistent data entry on all types of work. Clear expectations must be given to technologists and regular data review should take place with regular reports, daily dashboarding and supervisor follow-up. This is especially relevant to virtual asset use and project tracking where extreme variability in data entry was observed between technologists. This will also help better define project related tasks and improve the overall model.

4. Continued workload balancing: Data analysis revealed imbalances in technologists' assigned workloads. Some workload balancing has already taken place, but further effort should be made to make changes and communicate to technologists the inequities between each other's workloads. Discretion is required, and managers and supervisors should take into account technologists' feedback during this process and not rely solely on the model created in this paper.

5. Evaluation of models: If the proposed workload balancing and predictive staffing tools are to be used, their performance should be evaluated after some time. For instance, actual workload data could be compared to the predicted workload at the end of one year. These models will need to be updated as new devices are added to the CMMS.

6. Communicate with other organizations: Many of the surveyed organizations across the country seem to struggle with many of the same challenges experienced at TOH. Many interesting anecdotes and details about department strategies could not be included in this paper because of the sheer quantity of information. Organizations were eager to talk about their failures and successes. Opening a dialogue between organizations for occasional conversations could bring new perspectives and solutions into TOH and the broader clinical engineering community. This could take the form of an ad hoc forum created by CEDs themselves or perhaps a formal space created by a national body such as the Canadian Medical and Biological Engineering Society (CMBES).

VI. Conclusion

CEDs must constantly evaluate how to best use their resources to complete their work. Most operations have a high workload and must stay within an operating budget. This paper illustrated the common struggle for CEDs across Canada to meet the demands of their workload, especially PM compliance (Fig. 4, 5, 6). TOH is no different in this regard with a PM compliance of 50%.

Metric-based models may be one tool to understanding the scale of this workload and determining how to tackle it effectively. The novel metric-based models in this paper can be applied to TOH and other CEDs. Other organizations have also found success in adapting their PM program to suit the actual needs of their devices.

According to the staffing model described in this paper, TOH has roughly the correct number of BMETs employed and should be able to complete their expected work after balancing their workload using the workload balancing model described.

This makes TOH's 50% PM compliance difficult to explain. This low PM compliance could be due to the underestimated 10.3% project/miscellaneous, inefficient technologist workflows, or some other uncovered reason. Further investigation is needed to understand the reason for this discrepancy.

TOH should consider using a higher factor than 10.3% for project/miscellaneous work in their staffing model. As stated earlier, this estimate is almost certainly a significant underestimate. Until project and miscellaneous work is tracked more consistently, CMMS data should not be relied on for this factor.

CEDs create their own data and so should strive to create data that is accurate and consistent. As shown, this data can be crucial in creating and using models, evaluating technologist performance, planning for device acquisition, and advocating for more department resources. The clinical engineering team should work together on this goal, knowing that it will benefit the entire department.

Finally, CEDs across the country should look outwards and use other organizations as a resource. There seems to be a lack of data and knowledge sharing between hospitals even though the interest to do so exists. Collaborations between cities and even provinces could lead to growth and success for CEDs across Canada.

VII. Future Work

Future work could look at the feasibility and benefit of a new PM program for TOH. This could include risk-based PM schedules or evidence-based PMs from CMMS data. Liability and regulations should be taken into consideration.

Investigating possibilities for project tracking modules or creating an SOP for recording project time could be a smaller project that would help with collecting accurate CMMS data.

Finally, a cost benefit analysis of repairing vs. replacing low-cost device accessories could be performed. The surveyed organizations varied in how they manage their accessories. Some organizations repair their accessories, others replace their accessories, and some make it the responsibility of clinical floors to replace accessories. Accessory repair is one of the most common CM work orders logged at TOH. Surveying organizations to understand these processes and determine what the most cost-effective approach is for TOH.

VIII. Acknowledgement

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