Final Report of the Medical Equipment (ME) Uptime Project

March 2018

Project Symbol:
the winged snakes symbolizes healthcare, the screw driver tool represents technology and the up-arrow indicates the improvements that are pursued.

Author: Dr. Chris R. Mol
Biomedical Engineering Consultant
Tropical Health and Education Trust
Ministry of Health, DCCDD & DPPMT

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Millennium Development Goal Initiative
Accelerating the Reduction of Maternal, Neonatal and Child Mortality
MDGi: A Joint Programme of the Government of the Republic of Zambia – European Union – United Nations

Contents

1. Executive Summary

In 2017, The Tropical Health and Education Trust (THET) was requested by the Zambian Ministry of Health (MoH) to develop a pilot project to study the impact of the presence of well-trained, well-equipped Biomedical Engineering Technologists (BMETs) on the status of the medical equipment (ME) in level 1 hospitals. Since July 2017, THET, with the financial support of the UK Department for International Development (DFID) and the Millennium Development Goal Initiative (MDGi) project as sponsored by the European Union (EU) and managed by UNICEF Zambia, has supported the placement of eight BMETs in eight hospitals across four provinces.

BMETs were placed in hospitals which previously had no in-house medical equipment maintenance facilities. They were each provided with the tools to undertake professional corrective and preventive maintenance, simple test equipment and a laptop with monthly data bundles. Adaptations were made to existing workshops or rooms within the hospitals to ensure that a working-bench and stool, 220V electricity connections, water and sink, proper lighting and a lockable cabinet were available for the BMETs.

BMETs were first tasked to establish a baseline assessment in their hospitals and create an equipment inventory. This inventory was compared with the Zambian MoH standard equipment list for level 1 hospitals. Also, they mapped out the locally existing equipment maintenance procedures throughout the equipment lifecycle. The key finding of this exercise was that only 71% of available medical equipment was functional, that preventive maintenance and user trainings were not performed, and that English language user and service manuals were available for only 30% of the equipment.

In the following phase, BMETs took up corrective maintenance, preventive maintenance, and user training. From the baseline to the end of the project in February 2018, the BMETs managed to increase the medical equipment (ME) uptime within their hospitals from 71% to 93%. This had a significant positive impact on the healthcare delivery of the hospitals as manifested by the request of local hospital management to continue employment of a BMET after the end of the project. Systematic collection of data demonstrated that further improvements – to an estimated 98% ME uptime - can be achieved by making available a limited budget for spare parts.

A financial analysis of costs and benefits shows that the cost of placing a well-equipped BMET in a level I hospital is easily justified by the financial benefits. The investments will be paid back quickly through a decrease in the loss of value from dysfunctional equipment and an increased useable lifetime of the equipment.

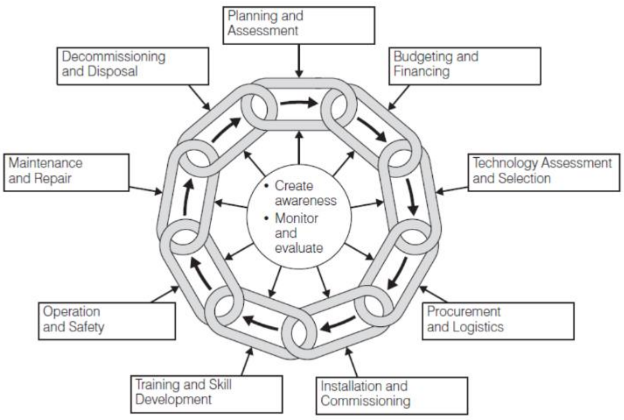
Extrapolating these results nationally shows that placing and supporting BMETs for in-house maintenance of medical equipment in all government hospitals in Zambia carries limited initial investment and has high benefits. Accomplishing this would require employing about 250 BMETs. Next to financial aspects, the associated clinical improvements are an additional bonus of developing in-house maintenance in all MoH hospitals.

It is further proposed that developing a systematic approach for procurement of new equipment throughout the country would diminish the large differences in availability of equipment at different hospitals and achieve a fairer distribution of equipment throughout the country. This would improve the equity of access to healthcare throughout Zambia and support the goal of universal health coverage.

2. Introduction

Between 20 and 50% of medical equipment (ME) is non-functional at any given time in many hospitals in Zambia and surrounding countries[i]. This has a significant impact on the quality of healthcare that is delivered to the patients and is financially inefficient as it means that large sums are spent on equipment that without maintenance will be unusable. This is a concern both for the Zambian Ministry of Health (MoH) and for cooperating partners (CPs) such as the UK's Department for International Development (DFID) and the UN Children's Fund (UNICEF).

One of the root causes for this situation is the lack of well-trained maintenance professionals in the hospitals. Until 2013, there was no training facility available in the country for dedicated Biomedical Engineering Technologists, when, at the request of the MoH and supported by DFID, the Tropical Health and Education Trust (THET) supported the development and implementation of the first diploma-level training program for Biomedical Engineering Technologists (BMETs) at the Northern Technical College (NORTEC), Ndola.



The Healthcare Technology Management Cycle[1]

The diploma curriculum ensures that the technologists trained can maintain medical equipment in a hospital setting, covering the full ME life cycle, from planning and procurement through to installation, commissioning, user training, corrective (CM) and preventive maintenance (PM) and ending with the decommissioning of equipment. All these activities are covered by the umbrella term 'health technology management', or HTM[1]. The first cohort of the BMET Diploma graduated from NORTEC in 2017. A second BMET training program, using the same TEVETA curriculum, has now begun at Evelyn Hone College in Lusaka. The first students are expected to graduate here in 2019.

With the availability of this new cadre, focus has shifted to utilising their skill and knowledge to make a difference to the medical equipment situation. With assistance from DFID and the MDGi programme, THET developed and implemented a pilot project to assess their potential. That is the topic of this report. The main purposes of this project were:

- to bring substantial improvements to the ME status in the participating hospitals.
- to understand the overall costs and benefits of setting up an 'in-house' maintenance service in a level 1 hospital.
- to identify further measures that can be taken to optimize the ME status in the hospitals.
- to increase awareness in the healthcare sector of the importance of professional ME maintenance.

The results of this project are presented in this report and are intended to establish the boundary conditions and the expected impact of setting up a professional, in house maintenance service for ME throughout the country.

[1] 'How to Manage' Series for Healthcare Technology: Ziken International (Consultants) Ltd, 2005.

3. Project Outline

During 8 months of the project, eight NORTEC BMET graduates have each been stationed in a Level 1 (‘district’) hospital: one BMET per hospital. BMETs were given a salary equal to what they would receive from MoH for the same function. Rural hardship allowances were added, where appropriate. The BMETs were requested to focus their actions on the district hospital. However, when time permitted also the health centres in the district were to be serviced as needed.

The project was supported by DFID/UK-Aid in two hospitals in Central province and two hospitals in Western Province and two each in Lusaka and Copperbelt provinces respectively supported by Unicef/EU-MDGi. See Appendix 1 for further details. The MDGi project had placed a significant amount of equipment in these district hospitals as well as in 4 of the district’s health centres. These centres have received special attention from the BMETs during the project.

The project was formally approved by the Permanent Secretary of the MoH and the selection of participating hospitals was done with the help of the Chief Medical Equipment Officer (CMEO) and the Provincial Medical Equipment Officers (PMEOs) of the associated provinces. Level 1 hospitals were chosen as they had no in-house ME maintenance facilities and were reliant on the provincial MoH office to fulfil their maintenance requirements. However, the ME maintenance capacity at the provincial level is insufficient to meet the needs of all districts. Furthermore, the quantity of ME in a Level 1 hospital could financially justify the presence of a full-time BMET. It was therefore expected that there would be significant impact implementing the project at this level.

Low-cost adaptations of an existing building or room were made to ensure that the newly placed BMET would have a proper work space. This included ensuring that they had access to a working-bench and stool, 220V electricity connections, water and sink, proper lighting and a lockable cabinet. In some hospitals this workspace would be a separate room, in other hospitals, the room was shared with electrical and/or other maintenance workers.

Further, a toolbox with a set of tools and some general-purpose consumables were provided on loan to each BMET. The contents of the toolbox is listed in appendix 2. BMETs were responsible for keeping the toolbox complete. In addition, a laptop with Microsoft Office was provided to each BMET as well as a dongle and a monthly data bundle (2-4 GB). To have access to an internet-connected computer is deemed essential for a professional BMET, both for data collection and organization, report making, locating information (e.g. manuals, maintenance methods) and communication with colleagues on solutions and progress.

Toolbox with tools as used in the project

A small amount of ME test equipment was procured. Test equipment is needed for ensuring that equipment functions well and is safe to use. For example: a device to measure oxygen concentration in a gas is required to measure the output of an oxygen concentrator. Without such a measuring device one cannot be sure that the oxygen concentrator is really working properly. Similarly, an electrical safety tester is needed to measure electrical leakage currents and to ensure that all isolation is functioning properly. In Zambia, the amount of test equipment is limited in comparison to international standard practice and vital checks for functionality and safety mostly cannot be undertaken. This is in part because national procurement priorities are focused on acquiring equipment to diagnose and treat patients. Since most test equipment is only needed from time to time, it is thought best to manage the available test equipment per province and lend it out to individual hospitals as needed.

The project consisted of the following phases:

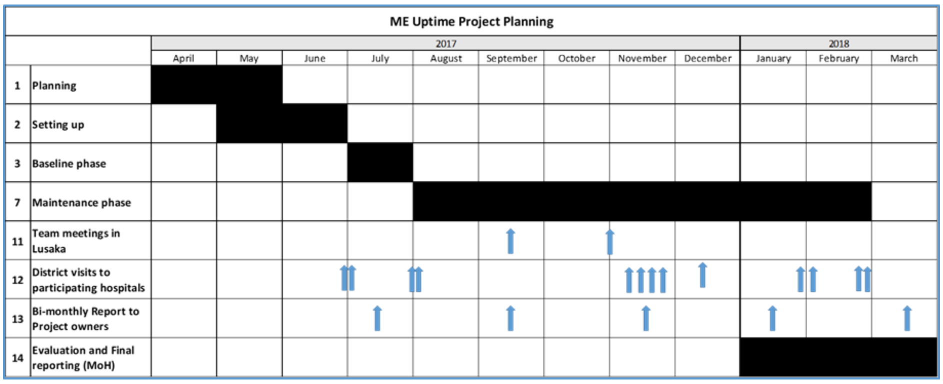
I. The planning phase to create the project plan and finalize budgets and contracts.

II. The setting up phase with selection and hiring of BMETs, selecting participating hospitals, procure tools, laptops and test equipment. A visit to each district and hospital to present the project to the local district and hospital staff and to define a suitable BMET work spot. Kick off meeting.

III. The base-line phase: during the four weeks of this phase, no corrective maintenance (CM) activities were carried out. The BMETs created an inventory of the hospital equipment and learned about the pre-project regime of equipment management, throughout the life cycle. They created a comparison between the actual equipment inventory and the standard equipment list. Further, they made an analysis of autoclave status and correlated this with the use of distilled water.

IV. The regular maintenance phase: in the first period of this phase the focus was on carrying out corrective maintenance (CM), i.e. repairing broken equipment, and decommissioning outdated equipment. In the next period work for preventive maintenance (PM) and user training was added. Throughout this period weekly and monthly reporting of activities was performed. Also, during this phase, a number of special activities were executed to acquire in depth information on other aspects of equipment management. These included: the establishment of requested medical equipment procurement priorities and a detailed analysis of the cause of broken down equipment.

V. The evaluation phase: in this period BMETs and project management analysed further causes of equipment downtime, e.g. spare parts provision, budget availability, user training, etc. This resulted in this report and the associated presentations.



Gantt Chart of the ME Uptime project

4. Monitoring and Evaluation

The project was designed with four targets:

1. To bring substantial improvements to the ME status in the participating hospitals.
2. To understand the overall costs and benefits of setting up in-house maintenance capacity in a level 1 hospital.
3. To identify further measures that can be taken to optimize the ME status in the hospitals.
4. To increase awareness in the healthcare sector of the importance of professional ME maintenance.

The main indicator used to measure results in this project is the percentage of uptime of the ME within the participating hospitals. The ME Uptime during a period is defined as the percentage of medical equipment that is functional in that period, where functional is defined as 'ready to perform its function'. Uptime is the complement of downtime. By definition: uptime + downtime = 100%.

Throughout the project, the BMETs were guided to carry out specific maintenance activities and to make regular recordings of the status of medical equipment in their hospital, their actual maintenance activities and the resulting ME uptimes. BMETs were provided with standardised reporting formats for weekly and monthly reports based on the data collected.

The participating hospitals were visited by project management twice during the intervention period. Firstly to inform district offices and hospital management about the project and to define the most suitable set up for a BMET work space. The second visit was to review progress and receive feedback from hospital management. In both cases the project team were joined by the PMEOs, it was originally envisaged that these PMEOs would regularly visit all BMETs during the normal course of their work. Unfortunately, in over half of the cases PMEOs were unable to undertake subsequent visits due to restricted funding for travel.

There were three participatory meetings for the BMETs at the THET office in Lusaka during the project where guidance was supplied, and progress presentations were made by the BMETs. These also provided an opportunity for sharing and learning between the BMETs.

In order to allow proper evaluation of the impact of the project, the first few weeks of BMET presence in the hospitals was devoted to establishing the baseline against which the intervention could be measured. This included compiling an inventory of all ME present within the facility and its current status. Each BMET was also tasked to identify existing procedures for medical equipment management and maintenance.

In collaboration with each facility a detailed plan for the creation of a BMET work space was made and quotations for associated building works gathered and put forward to project management for approval.

The ME inventory format used by the BMETs was taken from the MoH medical equipment management guidelines[2], with the following adaptations to provide further information to evaluate impact:

- The estimated initial price of the equipment: 'estimated value when new (USD)'
- The number of 'down days' for each unit in the past month, i.e. the total number of days in the previous month that the equipment could not be used for.

[2] Medical Equipment Management Guidelines, Republic of Zambia Ministry of Health, September 2012

5. Baseline Evaluation

As can be seen in the table below, the ME status overview at the end of the baseline period in July 2017 indicates that on average 89 ME units with an initial value of about $350,000[3] were present in the hospitals. The average age of the equipment was 8.7 years. While there was slightly more equipment originating from Europe there was a wide geographic spread. During the baseline assessment phase, the average ME uptime calculated by the BMETS was 71%. Many units had been non-functional for an extended time-period. Exacerbating these challenges, it was found that only 31% of the equipment had the corresponding user manual available in English in the hospital and only 23% had the service manual.

ME Uptime Project	**ME Status Overview**			
	District name			Month
	All Hospitals			**July 2017**
Equipment available	Number of Devices		Average age (# of years)	Est.value when new (USD)
	708	**89** per hospital	**8,7**	**350,000 USD /** hospital
Manufacturer Geography (% of equipment from each region)	Europe	USA	China/ India	Other
	34%	**12%**	**22%**	**31%**
Presence of equipment manuals in hospital (%)	User/operator's manual		Service manual	
	31%		**23%**	
Frequency of use: (% of equipment)	Every day	Few times per week	Few times per month	Not used
	49%	**24%**	**6%**	**21%**
Equipment unit numbers and condition	% of devices with 0 down days:	% of devices with 30 down days:	Total number of down days	ME Uptime
	71%	**28%**	**6.095**	**71%**

5.1 ME Uptime Baseline

Further analysis of underlying data indicates that the differences between the various hospitals are substantial, both in the unit numbers as well as in the value of equipment, the presence of manuals and the ME uptime. Even in the highest scoring hospitals 20% of equipment was found to be non-functional. Interestingly the hospital with the oldest equipment was found to have the best ME uptime. There was also considerable variance between the estimates of equipment value which can partly be explained by the different methods used to calculate these values (see further on).

Medical Equipment in:	# of units	Average Age	New Value	Manuals	ME Uptime
Chitambo	54	8.6 yrs	$332,000	31%	78%
Chongwe	119	4.8 yrs	$292,000	21%	73%
Kamuchanga	91	7.2 yrs	$361,000	44%	49%
Kaoma	96	8.7 yrs	$512,000	7%	75%
Liteta	134	10.1 yrs	$337,000	49%	72%
Lukulu	57	11.1 yrs	$164,000	20%	70%
Rufunsa	70	16.5 yrs	$272,000	24%	80%
Thomson	88	7.5 yrs	$499,000	9%	77%
Average	**89**	**8.7 yrs**	**$350,000**	**27%**	**71%**

Overview of the status of Medical Equipment as derived from the ME Inventory showing the baseline for all 8 participating hospitals

[3] see comments on pricing in section 4.7

Compared to the variance between facilities the ME uptime differences between different clinical departments are relatively small, with all departments on average scoring an ME uptime between 70% and 76%.

The ME uptime differences between different types of equipment was found to be considerable. For example, sterilisers, suction machines and lab centrifuges had a ME uptime under 50%.

Type of Equipment	Units	ME Uptime
Suction Machines	71	49%
Sterilizers (autoclaves)	50	46%
Blood Pressure machines	33	85%
Scales	47	94%
Lab Centrifuges	22	41%
Microscopes	32	75%
Resuscitaires	23	70%
Infant Incubators	26	
Oxygen Concentrators	27	59%
Refrigerators	31	84%
Total	**362**	

Table showing that the ME Uptime is widely different for different types of medical equipment (baseline data).

For the sterilisers the BMETs evaluated the water type being used. It was found that only 30% of the sterilisers in the participating hospitals were being operated with distilled water. Of those sterilisers 30% were non-functioning during the baseline evaluation compared to 70% for sterilisers operated with untreated (borehole) water.

The poor status of suction machines may well have been related to poor understanding of clinical users on how to use and perform daily care of these systems. Overflow of body fluids into the motor of the suction machine is a quite common complaint and should be prevented by a better equipment design or better user training.

An analysis of the relation between ME uptime and the place of manufacture, showed that ME uptime for equipment manufactured in China and India (158 units) had an ME uptime of 62% versus 74% for all other manufacturing locations (550 units). This was the case in spite of the China/India equipment being on average only 6.6 years old, versus 9.4 years for the other manufacturing locations. This confirms the general perception of workers in the field that the available equipment from these regions generally has poorer quality. It was also found that procurement of medical equipment from China and India is increasing: from all equipment in the field 22% is from China & India whereas for equipment obtained in the last 5 years, 31% is from these countries.

5.2 ME Baseline financial value estimate[4]

In defining the value of the equipment during the baseline measurement, price information was obtained by the BMETs mostly from the internet. Analysis showed that the pricing used was quite different between the different BMETs/hospitals. To increase the comparability of the project across hospitals, it was decided to use a single price list for the evaluation of ME inventory value. This price list was compiled from price lists as available at the MoH, consultation with BMETs in other African countries as well as data from the United Nations Office for Project Services (UNOPS).

Across sources procurement prices vary significantly. This is due to differences in equipment specifications, equipment quality and vendor costs and policies. It is estimated that a low cost/low quality version of a device costs about 50% of a high-quality/high-cost version of the same

[4] This value is an estimate of the initial procurement price of the equipment and does not account for depreciation. Considering the actual age of the equipment, the 'current value' of the equipment is considerably lower than the prices reported here.

equipment. For consistency the high-quality/high-price estimate was used to estimate inventory value.

This new approach in pricing resulted on average in a significantly higher price of about US$505,259 per hospital compared to the initial average of US$346,659. It also reduced the variation between overall equipment value estimates between the different hospitals. The uniform price estimates were used from the August ME inventory onwards. The updated price list will be actively maintained by the BMETs for future use.

5.3 Available Equipment

In 2012, standard equipment lists (SEL)[5] were developed at the MoH including the ME required by each department in a level I hospital. A priority level (one to five) is allocated to each item to indicate the importance of each device. Also, the required quantity of each type of device per department is listed.

During the baseline evaluation this list was compared to the equipment available in the hospital. To simplify the process, non-medical equipment was excluded, as was equipment below priority level 5. Quantity requirements were also excluded. This abridged list included approximately 100 units in 13 departments.

As the table shows Liteta Hospital had the lowest level of equipment present compared to the SEL with only 65% and the best performing hospital, Mpanshya only had 82%. Differences between departments in hospital were also high.

STANDARD EQUIPMENT FOR FIRST LEVEL REFERRAL HOSPITAL									
high priority (5) equipment only, plus dental, ultrasound									
Items	Presence at Hospital (1, 0) % of SEL present/ward								
	Chitambo	Liteta	Kaoma	Lukulu	Chongwe	Mpan shya	Thomp son	Kamu changa	Average
OPD and Casualty	42%	42%	67%		50%	50%	75%	25%	50%
Dressing and Injection Room		67%			100%				83%
all Wards Except Maternity	78%	78%	89%	67%	44%	100%	67%	22%	68%
Labour Ward and Maternity	54%	62%	62%	46%	38%	77%	54%	69%	58%
Post Natal Ward	33%	67%	67%	33%	67%	100%		67%	62%
Various Parts of Maternity	100%	67%	100%	100%	67%	100%	33%	100%	83%
Operating Theatre	85%	62%	77%	54%	85%	85%	69%	92%	76%
Sterilisation Room	100%	75%	50%	25%	100%	75%	100%		75%
Dental	60%	30%	60%		60%	50%		60%	53%
Pharmacy	50%	50%	50%	100%	50%	100%	100%	50%	69%
Medical Laboratory	71%	88%	82%	65%	100%	76%	88%	82%	82%
Miscellaneous		100%	100%	100%		100%		100%	100%
Medical Imaging	67%	58%	83%	83%	75%	75%	58%	75%	72%
Average	67%	65%	74%	67%	70%	82%	72%	68%	72%

Table showing the presence of ME in each department and each hospital as a percentage of the reduced Standard Equipment List (baseline data).

Further analysis of the data was hampered by the fact that not all hospitals have the same departments. For example, in some hospitals the Dressing and Injection room is integrated with the OPD, some hospitals have no dental department and some hospitals are in the process of moving or re-organizing.

A detailed department level analysis in the different hospitals brings up some striking facts:

[5] Standard Equipment Lists, Publications of Zambian MoH, September 2012

- STANDARD EQUIPMENT FOR HEALTH POST, HEALTH CENTRE AND LEVEL 1 HOSPITAL
- Medical Equipment Standard Lists for 2nd Level Hospitals
- Medical Equipment Standard Lists for 3rd Level Hospitals

- There is a great shortage in CardioTocoGraph (CTG) machines, with only two of eight hospitals having one and foetal heart monitors (3 out of 8) to support child delivery.
- Phototherapy units ('blue light'), which can prevent serious brain damage in new-borns with not uncommon hyperbilirubinemia, were available only in 3 out of 8 hospitals.
- Defibrillators were available only in 5 out of 8 hospitals
- A diagnostic set (ophthalmoscope and otoscope) was only available in one of the hospitals
- Only 3 out of 8 hospitals have sufficient dental equipment to enable the filling of teeth.

Diagnostic set for eye, ear and nose exams

The ME inventories includes equipment that was non-functional. Therefore, if 72% of the SEL was available and the ME uptime is 71%, on average only 51% (72% x 71%) of the SEL was available and functioning during the baseline evaluation.

5.4 ME maintenance procedures at the hospitals

During the baseline evaluation BMETs evaluated the existing procedures for medical equipment in their respective hospitals. They looked at planning and acceptance of new equipment, PM and CM the monthly procurement of spare parts and consumables and decommissioning. For more information on this: see [6].

New equipment planning

An action plan for the procurement of new equipment is supposed to be made every three years and revised quarterly. This process involves each department completing a form indicating needs which is submitted to hospital management and then to the MoH. For urgent procurement needs, hospital management submits requests to the district office which are then forwarded to the provincial level and the central MoH. Most equipment procurement is executed at the central level.

Challenges often faced include insufficient sums being allocated to the hospital from the central level leading to hospital management lobbying partners or using donor funds when available. Generally, limited information is provided to hospitals on the procurement process and timeframe leading to deliveries arriving unexpectedly.

New equipment acceptance

When new equipment arrives, it is checked by the store's manager. Once checked it is recorded in the store's ledger, with a Goods Received Note, containing information such as the supplier of the equipment, the department it will be taken to and the price of the equipment. Usually, the acceptance procedure is limited to unpacking and taking the equipment to the respective departments.

Monthly procurement of spare parts and low-cost equipment

Hospitals are given a grant every month by the MoH for running costs. This includes procuring small equipment including blood pressure machines, thermometers, glucometers, consumables as well as the necessary spare parts. Actual priorities are determined each month by the finance committee. Approval for spare parts procurement depends on the urgency of the equipment repair, for instance if it interrupts normal hospital procedures, as well as on alternative needs for the funds e.g.

[6] 'Health Technology Management in Zambia, a mapping exercise in Copperbelt Province' Shauna Mullally, April 2017

medicine, food, staff allowance etc. Urgent equipment includes laboratory equipment and theatre equipment, such as anaesthesia machines.

When requiring spare parts or consumables, a request is made in form of a memo or a request form is sent to the medical officer in charge or the procurement officer. When approved, the memo is passed on to the purchasing officer, who will work with the BMETs to ascertain prices and other specifications to come up with a quotation. When approved, the request is then taken to the finance committee, consisting of the hospital administrator and the head of each department. When again approved, the finance officer issues a cheque to the procurement officer who then buys and takes the items to main stores. The BMET will then use a supply voucher to collect the items from stores. If the cost of procurement is less than one hundred kwacha, the procurement may be done by 'petty cash', which can be released by the financial officer immediately. All equipment that is above 15,000 Kwacha must be tendered. Below this, procurement is often done via direct order.

Spare parts for less urgent equipment often have to wait for approval until the next grant comes in. Such postponements can be repeated for many months.

Corrective Maintenance

Every Friday the hospital files a report to the district office about the operations of the hospital. This includes breakdowns of medical equipment. Once the district receives the report it is sent to the province, then the province sends its technicians to come and work on the equipment. The provincial response depends on the funds and whether the breakdown is an emergency. If the breakdown is not deemed to be an emergency the response may take many months.

For some repairs a third-party service provider is contacted. The period that such a service provider takes to arrive depends on the budget of the hospital and how busy the company providing the service is. The hospital pays for the service, and if necessary, transport and accommodation.

Preventive Maintenance

Technicians from the province did not have the capacity to undertake PM as they were responsible for the repairs in all district hospitals in the province.

Hospitals may have a long-term service contract with the vendors that supplied the equipment, for example this is often the case for laboratory equipment. These vendors have their own program with regards to servicing of the equipment with service warranties. They come at least twice per year to carry out PM on the equipment. They also may be called upon whenever one of their equipment units develops a fault.

Decommissioning

When equipment becomes non-functional it is put aside, with no further action taken regularly. Periodically, personnel from the Ministry of Works and Supply come to decommission equipment, auctioning obsolete equipment.

5.5 Analysis of Baseline

The presented results suggest that the poor status of medical equipment in the participating hospitals is caused by an historic lack of accountability with no well-trained individual responsible for the status of medical equipment. This is the root cause of such ME limiting factors as missing service manuals and service history files, a lack of user training, a lack of PM, unprofessional CM and unsystematic ME management.

MacGyver is a well-known TV character in Zambia. He generally is a hero for technical people. However, he should not be a role model for Biomedical Engineering Technologists!

On the poorer status of some equipment: it is suspected that current (MoH) procurement practices lead to selection of poor quality and low-cost equipment. Such equipment usually comes from ‘low cost manufacturing countries’ such as China and India. These countries are known to produce also higher-end equipment, which apparently is not selected. It is suggested that procurement procedures should be reviewed and improved, so that these are not biased towards procurement of low cost / low quality equipment.

6. Implementation Phase

After the evaluation of the baseline was completed in August 2017 the BMETs started to undertake regular maintenance at their hospitals. There was an initial focus on CM; towards the end the focus was more on PM and User training. Systematic record keeping was maintained throughout the project.

6.1 Activity reports

Standard administrative procedures around equipment maintenance require that a job card (form) is filled in for each CM and for each PM action. The format of the job card has been defined in MoH guidelines.[7] These forms are paper based and with different sections that require input from several people including clinical users, administrators and BMETs. While this paper form used to be suitable for implementation in low-resource settings they do not allow for easy analysis or evaluation, for example highlighting patterns of common breakdowns or corrective measures taken. For this reason, in the ME uptime project BMETs were requested to maintain separate electronic activity reports.

The activity reports included many details on each of the CM and PM jobs, including time taken on different activities as well as customer complaints, root causes, main fixes, materials needed, and

[7] Developed with the Japan International Cooperation Agency, 2012

success achieved. To ensure comparability of results across hospitals this information was selected from drop down menus.

6.2 Corrective Maintenance

Corrective maintenance is about repairing equipment that is not functioning, partially functioning, or unsafely functioning.

The main root causes of equipment breakdown turned out to be the malfunctioning of an electrical component (28%) or a mechanical component (15%), power supply problems (13%), user errors (13%) and dirt collection (10%). The main repair actions were: replacing components (23%), soldering or gluing (15%), cleaning and lubrication (12%), adjustment of settings (9%) and user training (3%).

On average there were 2.2 CM actions per hospital each week, totalling 526 CM actions for all hospitals involved in the project. This is thought to be high in comparison to the total number of ME units in the hospitals: 756 pieces. This high incidence may reflect the average old age of the systems.

The number of CM actions in the first three months (Aug-Oct) was 2.9 per week, while in the last four months (Nov-Feb) it was only 1.6 per week. This reflects the high number of non-functional systems that needed repair at the start of the project. It can be expected that over the longer run, the number of CM actions will go down further. This underlines the message that a good BMET is not so much a repairer of equipment but a manager in charge of preventing equipment breakdown in the hospital.

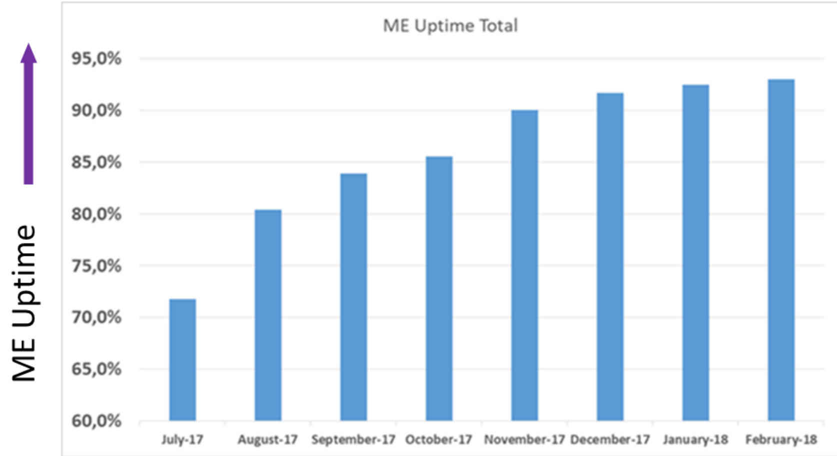
Diagnosis of faults took on average 0.7 days and while most equipment was repaired and returned to clinical users within a day, the average length of time for returns was two days. This can be explained by the CM activities requiring the procurement of parts, which could take several weeks.

Spare parts procurement										
	parts to be procured by hospital					parts to be obtained via Province				
	# requested	value requested (USD)	# received	value received (USD)	average # days order to receive	# requested	value requested (USD)	# received	value received (USD)	average # days order to receive
Kaoma	3	1.665	1	1.380	2	1	400	0	0	x
Lukulu	22	1.306	8	106	14	0	0	0	0	x
Rufunsa	12	1.000	4	527	3	1	4.000	0	0	x
Chongwe	26	480	12	121	6	0	0	0	0	x
Chitambo	5	1.045	2	7	15	4	2	0	0	x
Liteta	19	870	3	740	9	1	700	0	0	x
Luanshya	35	430	29	197	5	0	0	0	0	x
Mufulira	17	2.287	7	1.040	10	3	637	0	0	x
Total	139	9.083	66	4.118	8	10	5.739	0	0	

Table showing the facts around procurement of spare parts for medical equipment in the project. Only 66 out of 139 parts requested were actually received during the course of the project.

Procurement of components was needed in 30% of cases, however in only 44% of these cases (=66 parts ordered) was this procurement accomplished within the project period. In those cases, it took on average 8-9 days for components to arrive. The total value of the requested procurements was US$9,083 and the total value of the received procurements was US$4,118. In ten cases, support was requested from the PMEO to procure spare parts for international equipment with a total spare part value of US$5,739. None of this was delivered before the end of the project.

During the project period, the ME Uptime increased from 71% to 93%. It took 4 months, from the start in August, to reach the 90% ME Uptime level by end of November. After that period, the graph flattens out.



At the end of the project a ME Uptime of 93% was achieved. This means that 54 ME units were still broken. A detailed analysis of these units shows that this is caused by:

- Waiting for procurement: 69% (37 units)
- Waiting for decommissioning: 13% (7 units)
- Regular repair ongoing: 11% (6 units)
- Not able to find cause: 4% (2 units)

6.3 Preventive Maintenance

PM was implemented from October 2017 onwards according to a schedule that each BMET made at that time. PM actions per equipment were scheduled to be repeated twice a year, unless explicit specifications were found in the service manual.

In total, 252 PM actions were carried out in the project, which were mostly the first times that ME in the hospitals had had any PM. The average duration of a PM action was measured to be 77 minutes. 93% of PM actions were successfully completed without significant problems. 12% of PM actions used consumables and in 6% of PM cases, it was discovered that further CM activity was required.

6.4 User Training

User error was regularly cited as a cause for non-functioning ME. The need to give user training was left to the judgement of each individual BMET. For this project user training was defined as a session that was led by the BMET, lasted for at least 20 minutes, and was attended by at least 3 users.

Over the course of the project 84 user trainings were undertaken at the hospitals and health centres, on a variety of types of ME, including amongst others autoclaves (21 training sessions), resuscitaires (17), infant incubators (17), oxygen concentrators (7), Doppler foetal monitors (3), suction machines (3), nebulisers and ultrasound systems (3).

User training at Chongwe Hospital

6.5 Installation of New Equipment

On average, five new installations were performed per district. The districts supported by the MDGi project received the most new equipment, an average of more than 7 pieces compared to 2 in other districts.

To maintain an installed base with a value of US$350,000-500,000 and an average life time of 10 years it is necessary that a hospital receives yearly medical equipment with a value of at least US$35,000-50,000. Those hospitals that were not part of the MDGi project received on average US$2,856 during the project.

Equipment Commissioned during project			
		#	value (USD)
MDGi project	Mufulira	4	17.500
	Thomson	6	71.500
	Chongwe	12	55.000
	Rufunsa	7	66.500
	Average	**7,25**	**52.625**
Other	Kaoma	3	7.000
	Lukulu	3	3.300
	Chitambo	1	400
	Liteta	2	760
	Average	**2,25**	**2.865**

In addition, several smaller new units were received/procured that did not require formal commissioning. During the project, a number of units were discovered by BMETs in their hospitals that were already present but not in use. Several decommissioning actions were executed. As a result, the average number of devices available in the hospitals has increased during the project from 89 to 95 devices. However, the amount of ME in the participating hospitals is still much lower than indicated in the SEL as necessary for good patient care.

6.6 Procurement priorities

In October BMETs reviewed the procurement priorities within each department of their hospitals and compiled lists of needed items. It was noted that in most cases, such priority lists were not yet available at the departments, despite reported procedures.

An attempt was made to analyse the correspondence between these priority lists and the Standard Equipment List (SEL) comparison that was made as part of the baseline analysis. However, this turned out to be complicated. The following reasons were identified for this:

- The procurement priorities of the departments were not always restricted to the lists of items that the department was supposed to have at this level of hospital (standard equipment list). Departments found the choice in this SEL not wide enough. Sometimes equipment that is indicated for higher level hospitals was prioritized.
- Sometimes equipment that was already present at the department was still prioritized for new procurement. This was especially the case for currently available equipment that was not functional.
- Hospitals tended to overlook ME that was on the standard equipment list but not within use of the hospital. It appeared that they had learned/accepted to do without some of this equipment.

It was noted that there was little correspondence between the priorities of the departments and the equipment that was actually procured for them by the MoH procurement activities.

6.7 User and Service Manuals

	July 2017		February 2018	
	User manual	Service manual	User manual	Service manual
Average	31%	20%	57%	43%

During the project an extra effort was made to identify more user and service manuals of the equipment in the hospitals. This included searches inside the user departments in the hospital as well as online. This has resulted in an almost doubling in the number of manuals. It is suggested that the available manuals will be posted on a website from either MoH or the BEAZ (Biomedical Engineering Association of Zambia), so that these become easily available to all BMETs in the country.

7. Financial analysis

Some key financial observations and estimates as made in the project are presented in below table. This analysis relates to the period up to January 2018. Further background info on this is presented in Appendix 3.

#	Parameter	**All 8 hospitals**
1	The estimated total initial value of the medical equipment:	2.8 M.USD
2	The estimated total initial value of the medical equipment under 3rd party maintenance contract:	1.2 M.USD
3	The total initial value of the medical equipment to be maintained by 'In House' maintenance (#1 - #2):	1.6 M.USD
4	The percentage of all equipment under 'In House' maintenance that was not functional at the start of the program:	28%
5	The value of 'in House' maintained equipment that was not functional ('down') at the start of the project:	580,000 USD
6	The percentage of 'In House' maintained equipment that was not functional at the end of the program:	7.5%
7	The value of 'In House' maintained equipment that was down at the end of the project:	280,000 USD
8	The cost of procurement of parts used to repair broken equipment:	3,200 USD
9	The salary cost of providing maintenance, BMET salaries over 7 months @ 5,000 USD/yr	23,500 USD
10	Cost of tools, workshop was: 15,000 USD/5 yrs. Depreciation of these costs over the project period:	1,750 USD
11	Total maintenance costs (#8+#9+#10) during the 7 months of the project:	28,450 USD
12	Total maintenance costs extrapolated over 1 year: 12/7 x #11:	48,800 USD

13	The Cost Of Service Ratio (COSR, see Appendix 4) for the In House maintenance was therefore: (#12/#3):	3,0%

Equipment depreciation wasted

The fact that equipment with a value of US$580,000 (table row #5) was 'down' at the start of the project constitutes a significant loss. This is because depreciation continues also if the equipment is down and no clinical value is created during this down time. With an average 10-year life time this depreciation loss can be estimated at US$58,000/year. If good maintenance lowers this amount to US$280,000 (table row #7) then the wasted depreciation will be 'only' US$28,000/year. This means that the presence of good 'in House' maintenance is saving US$30,000/year. This pays for a good part of the cost of doing the maintenance (table row #12).

Note: the relatively high value of broken equipment at the end of the project period is heavily impacted by a number of expensive autoclaves which have not been fixed during the project. This underlines the need for the use of distilled water in all autoclaves.

Equipment life time increase

On top of this, ongoing maintenance will prolong the life time of the equipment e.g. from 6 to 12 years. This halves the yearly depreciation of the equipment. Estimating the value of this:

- With 6 years life time the depreciation value of the In-House equipment is US$1.8 Million / 6 = US$300.000/year.
- With 12 years life time the yearly depreciation value is US$150,000/yr.

That means that on a yearly base, with an investment of US$48,800/yr (table row #12) a value of US$150,000/year is generated through increasing the equipment life time.

Total financial value created

In total, we conclude that in seven months the total maintenance costs of **US$28,450** have generated: **US$17,500** through reduced down time + **US$87,500** (7/12x US$150,000) through increased life time = **US$110,000**. Therefore, we can state that the project has demonstrated that a high value can be created through setting up proper 'in-house' maintenance.

On top of this, BMETs in the project have added value via equipment maintenance in surrounding health centers as well as via occasional maintenance of non-medical equipment including air conditioners, laundry machines, electricity generators, etc.

Clinical value created

Next to the financial aspects, the significant increase in ME Uptime associated with the presence of a well-equipped BMET has delivered a better and more efficient hospital operation. A higher ME uptime/availability increases access of patients to the equipment related procedures and diminishes inefficiencies such as those arising from the need to reschedule patient visits when equipment breaks down. Unsurprisingly, hospital management in all hospitals involved was found to be eager to maintain BMET presence after the end of the project.

8. Setting up in-house maintenance throughout Zambia

The MoH in Zambia has published 'Standard Equipment Lists'[8] that describe in detail what medical equipment is targeted to be present in the different levels of hospitals. From this it has been estimated what the total procurement value of ME per hospital would be if all targeted equipment would be in place (see table below).

	Estimated value of medical equipment in standard equipment list (US$)	Number of health facilities (NHSP 2017-2021)	Total targeted procurement value of medical equipment (US$)
Health post	9,000	1,839	16,551,000
Health Center	20,000	953	19,060,000
Level I	400,000	99	39,600,000
Level II	1,500,000	34	51,000,000
Level III	3,000,000	8	24,000,000
TOTAL		**2,933**	**150,211,000 USD**

Combined with the total number of the different types of health care facilities as mentioned in the National Health Strategic Plan 2017-2021[9] it is estimated that the total amount of equipment that is targeted to be in all health facilities together is around US$150 Million. It must be noted that this number is just a ballpark figure considering the huge variations in equipment models as well as equipment quality and pricing.

In reality, the available medical equipment will have a lower procurement value than indicated in the table because not all equipment in the standard equipment lists is actually present in the hospitals. For use in this discussion, we will assume that the total procurement value in all hospitals together is in the order of 100 Million USD.

Next, we will assume that, in line with the project findings, 42% (in value) of this equipment has a high level of technical complexity and is maintained via third party maintenance contracts. Taking the estimate of 5% COSR, this leads to a required budget amount for such contracts of US$2.1 Million/year. Note that a good part of this is paid via chemical reagents contracts (that include equipment maintenance) for Laboratory analysers. Therefore, the maintenance part of the other medical equipment under contract should be significantly lower.

The remaining 58% of medical equipment with a value of US$58 Million falls under 'in-house' maintenance. As mentioned above, the current budget for this maintenance is very low and the associated ME uptime is poor. In line with the findings in the ME uptime project as described above, we will here present a proposal to install a professional maintenance service and calculate the business case for this situation.

[8] Standard Equipment Lists, Publications of Zambian MoH, September 2012
Standard Equipment For Health Post, Health Centre And Level 1 Hospital
Medical Equipment Standard Lists for 2nd Level Hospitals
Medical Equipment Standard Lists for 2nd Level Hospitals

[9] Zambia National Health Strategic Plan 2017-2021, Republic of Zambia, Ministry of Health

Proposed 'in-house' ME maintenance service

The proposed budget to be spent on in-house equipment maintenance consists of the following:

- Salaries for BMETs:
  - Every level 1 hospital to employ 1 BMET.
  - Every level 2 hospital to employ 3 BMETs.
  - Every level 3 hospital to employ 6 BMETs.
  - Total number of BMETs based on hospital numbers in the table above: **249 BMETs**.
  - Estimated integral salary costs/BMET: US$5,000/yr.
  - **Total Salary costs: US$1,245,000/yr**.
- Spare parts:
  - Estimated at **US$200,000/yr**.
- Depreciation of fixed costs:
  - BMET Tools: US$500 toolbox depreciated over 5 years: US$100/yr/BMET
  - BMET PC's: US$600 depreciated over 4 years: US$150/yr/BMET
  - BME Workshop: US$1,000/BMET depreciated over 10 years: US$100/yr/BMET
  - Total yearly depreciation per BMET: US$350/yr/BMET
  - **Total Depreciation costs**: 249 BMETs x US$350/BMET/yr = **US$87,150/yr**.

Adding up, the national in-house maintenance cost of this proposal will be (1,245,000 + 200,000 + 87,150) = **US$1,535,000**. As a percentage of the initial value of the equipment to be maintained in-house (US$58 Million) this gives an estimated **COSR 2.8%** which is well below international standards (see Appendix 4).

This yearly budget will result in the following:

- Proper functioning of US$52 Million of medical equipment with a better than 95% medical equipment uptime.
- Avoidance of the current waste of broken equipment which brings a wasted depreciation of 30% of US$52 Million over 10 years' time => US$1,56 Million/yr.
- A significant extension of the life time of the equipment. If all equipment lives 2x as long, maintenance creates a yearly value of US$10 Million.
- A much better healthcare system with 95-70=25% higher ME Uptime and fewer disturbances in clinical operation.

9. Discussion

Evaluating the results of the project versus its original targets, we come to the following conclusions:

Target 1: to bring substantial improvements to the ME status in the participating hospitals

The ME Uptime project has demonstrated convincingly that the work of graduated BMETs in District hospitals had a very positive impact on the status of the Medical Equipment in these hospitals. The ME Uptime increased from 71% to 93%. This means of the 756 ME units only 54 were non-functioning at the end of the project. Apparently, the NORTEC BMET diploma training is adequate for its purpose. In line with this, the management of the participating hospitals were very positive on the presence of a BMET and have all stated that they wanted to keep this asset.

Target 2: to understand the overall costs and benefits of setting up an in-house maintenance facility in a level 1 hospital

The negative financial impact of poor maintenance of medical equipment is mainly caused by two factors:

1. the lost value due to depreciation of the equipment during the time that it is not functioning and
2. the reduced life time that is the consequence of poor maintenance.

In section 7 it was analysed that the increase in ME uptime in the project had reduced the loss of value due to depreciation by over 50%, representing a saving of US$30,000 per annum. Additionally, US$87,500 was estimated to be saved through expected increase in equipment life time. When this is offset by the various costs in the project a net gain over all 8 hospitals is estimated of US$76,550

Aside from the financial benefits to in-house maintenance, the reduced down time of equipment will improve the diagnostic tools and treatment options available to patients. The reduction in unexpected breakdown will lead to a more plannable hospital operation.

It has become quite clear that it is inefficient to procure equipment and not allocate funding for its maintenance. An approach has been proposed for the MoH to implement a national in-house maintenance infrastructure.

Target 3: to identify further measures that can be taken to optimize the ME status in the hospitals.

A significant further improvement in ME uptime could be achieved by allocating a spare parts budget to each district or province. As estimated in section 5.1, it would only cost about US$10,000 for the 8 hospitals to fix another 37 units. This comes down to US$270 per unit which is certainly much less than the cost to replace these units. Such a spare parts budget would lead to a ME uptime of 98%. As known from management theory (see figure), without an explicit and dedicated budget for spare parts, management will always choose urgent matters over strategically important matters.

'Covey's matrix' suggests that the best way to make sure that non-urgent but important matters will be seen to is to plan/schedule them. In the case of ME management this suggests setting a budget aside for important – but not always urgent - equipment maintenance.

An increase was achieved in the user and service manuals available to clinical staff and BMETs from 31% and 20% respectively to 57% and 43%. This included searches inside the user departments in the hospital as well as online. It is proposed that available manuals are posted on the website of the MoH and/or the Biomedical Engineering Association of Zambia, so that these will be easily available to all BMETs in the country.

Water distiller

The lack of distilled water for use in autoclaves is shown to be a major cause of breakdowns. Since the cost of a water distiller is low in relation to the cost of the number of autoclaves in a hospital, the procurement of a distiller or otherwise the access to distilled water should be high on the priority list for hospitals. It is noteworthy that none of the clinical departments has prioritized the procurement of a water distiller.

The amount of medical equipment in the participating hospitals is much smaller than the standard equipment list indicates is necessary for good patient care. On the one hand, this can be ascribed to the fact that the Zambia is a low/middle income country (LMIC), and that available funding is limited. On the other hand, the data suggest that this may be impacted by how available funding for medical equipment is distributed over different hospitals.

Since there is currently no national overview and analysis of equipment in different hospitals it is not possible to make systematic procurement allocations. Even if this was available, there is currently no policy on how to allocate spending for equipment procurement to different (levels of) hospitals. As a conclusion, current equipment distribution appears to be dominated by the CP projects that donate equipment as part of their targeted projects in their allocated provinces. By their nature, these projects have a limited scope and do not lead to the hospital fulfilling their wide needs for medical equipment.

A six month period during which preventive maintenance activities are carried out – as in this project - is too short to adequately measure its impact on ME uptime. Still, from literature it is clear that preventive maintenance is crucial in reducing the number of break downs in a hospital. This could be investigated and further detailed in a follow up of this project.

This project has provided valuable insights into the root causes of the breakdowns and the main methods that are needed to remedy the situation. Next to the high level of normal wear and tear that can be expected with old equipment it has become clear that an increase in daily and weekly user care would be of significant benefit for the equipment as a significant proportion of equipment becomes non-functional due to dirt as well as by user operator errors. Ongoing user trainings and PM will be an important part of BMET work in these hospitals.

Target 4: to increase awareness in the healthcare sector of the importance of professional ME maintenance

From feedback to several formal and informal presentations given and documents distributed, it is felt that progress has been made in this respect. Certainly, the awareness in the participating hospitals and amongst the BME community is high. The currently advocated proposal to set up a full in-house maintenance system in the country is received positively by MoH as well as a number of CPs.

Finally

ME procurement without maintenance is wasteful

As guidelines for procurement of medical equipment in Zambia the following financial conclusions can be drawn from the project results:

- For every US$1,000 that is spent on procuring a medical device that is to be maintained 'in-house', another US$28/yr (2.8% COSR) should be budgeted to cover the life time cost of maintenance. Over a 10-year period this adds up to US$280, which is an additional 28% on top of the procurement value of the medical equipment itself. The total investment should therefore be raised to US$1,280. Alternatively, from a US$1,000 budget for medical equipment only US$781 should be spent on procuring new equipment with the other US$219 being allocated to maintenance.
- For funds spent on equipment that will be maintained with a contract from a 3rd party maintenance provider, a higher budget of at least 5% per year should be reserved. It requires more research to find a good benchmark for this COSR percentage in Zambia.
- It is currently not correct to assume during equipment procurement that such maintenance budgets are already covered in general GRZ budgets.
- If these maintenance costs are not included, the equipment life-time will be reduced by a factor of 2: the value of the US$1,000 donation will be reduced to US$500. Also, it must be assumed that the uptime of this equipment will on average be only 70%, so that the donation value of US$1,000 goes down to US$350 (70% of US$500).

A nationwide in-house ME maintenance service is required

As a further general conclusion from the project it is suggested that setting up 'in-house' maintenance in all hospitals in Zambia as proposed above will be a very beneficial activity, both financially and clinically:

- Healthcare delivery to patients will be better and functioning of hospitals will be more undisturbed. This will be gratifying for healthcare staff and patients.
- The cost of the maintenance program will be outweighed by the reduced waste of broken medical equipment.
- The increased life time of well-maintained equipment will lead to a much-reduced need for the procurement of new medical equipment to replace the broken equipment.

Also, the benchmark COSR demonstrates that with this proposal Zambia (COSR = 2.8%) will have a lean and effective ME maintenance service.

Systematic allocation of ME procurement would be fair

Finally, it is proposed that developing a systematic approach for procurement of new equipment throughout the country would diminish the large differences in availability of equipment at different hospitals and achieve a fairer distribution of equipment throughout the country. This would improve the equity of access to healthcare throughout Zambia and support the goal of universal health coverage.

Appendix 1: Participating hospitals, BMETs and PMEO's

Selected hospitals: Central Province

Chitambo Hospital

BMET
Ms. Patricia Kululuma

Liteta Hospital

BMET
Mr. Kaluba Katati

PMEO Central Province
Mr. Timothy Mukoko

Selected hospitals: Western Province

Kaoma Hospital

BMET
Mr. Peter Mulenga

Lukulu Hospital

BMET
Mr. Elijah Muwandia

PMEO Western Province
Mr. Elias Luhanna

Selected hospitals: Copperbelt

Thomson Hospital Luanshya

BMET
Mr. Shasa Mupeta

Kamuchanga Hospital Mufulira

BMET
Mr. Snezan Petimoya

PMEO Copperbelt Province
Mr. Patrick Mumba

Selected hospitals: Lusaka Province

Chongwe Hospital

BMET
Mr. Anderson Phiri

Mpanshya Hospital (St. Luke)

BMET
Mr. Peter Magawa II

PMEO Lusaka Province
Mr. Chris Sinkala

Appendix 2: Tools and Consumables

BMET Hospital Toolbox

	Tool	configuration	Picture
1	Allen Key Set	3 sets required: metric, inches & torx	
2	Screw Driver Set	2 sets required: blades and phillips	
3	Screw Driver Set Precision Type	set to include blades and phillips	
4	Voltage Function Screw Driver		
5	Wrench set	instead of adjustable wrenches	
6	Multi Function Key		
7	Plumber's Pliers		
9	Long Nose Pliers		
8	Short Nose Pliers		
10	Diagonal Cutter (Big)		
11	Diagonal Cutter (Mini)		
12	Adjustable Wire Strippers	adjustable or with different sctions	
13	Pen Knife		
13	Hacksaw (Big)		
14	Hacksaw (Mini)		
15	Torch	LED, to include batteries; or rechargeable	
16	Measuring Tape		
17	Brush	2x: small and big	
18	Steel Toolbox		
20	File Set	2 sets: small (for keys) and big	
19	Hammer		
21	Soldering iron	with a durable coated tip	
22	Helping Hand for soldering		
23	Magnifying Glass		
24	Solder Sucker		

Consumables included: O-Ring set, Zip tie Set, WD 40 lubricant, solder with flux Sn60/Pb40, Glue(s), Duct Tape 48mm x 25m[10]

[10] BMET requests for further tools include: a large adjustable wrench, an (industrial) blower, an open end wrench set at least 6-22mm, a chisel, a 100w soldering gun, safety goggles, a driller and drill bit, tubing scissors.

Appendix 3: Background info on ME maintenance in Zambia

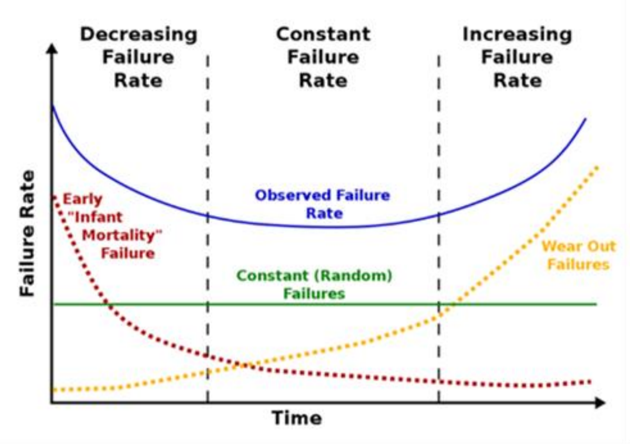
Introduction

Medical equipment is an indispensable part of modern healthcare. Innovations in medical equipment have contributed to improved diagnostic, therapeutic, monitoring and rehabilitation procedures. Looking at healthcare from a financial perspective, a part of the healthcare budget will therefore be allocated to medical equipment. It can be argued that if money is spent on medical equipment it is essential to also allocate a budget to the maintenance of this equipment. Without this, a good part of the value of the medical equipment investment will be wasted.

Economically, medical equipment is considered to be a capital good. That means that the cost of the device is spread out (depreciated) over the life time of the equipment. For example, if the procurement cost of a device is 12,000 USD and it has a life time of 10 years, it is considered to cost 1,200 USD/yr or 100 USD/month. For every month that this device is broken, the un-used (wasted) value is 100 USD.

All equipment has an expected life time. This life time depends on the type of equipment and the type of technology it contains, such as electronics and mechanics. At any time during the life of the equipment, parts can fail due to wear and tear. Five years is a typical life time for an ECG monitor, ten years for a suction pump and 15 years for an operating table.

The bathtub curve (see Figure) describes the typical failure rate of medical equipment over its life time. In the first period after installation, the failure rate is relatively high, due to early system failures and user errors related to user's unfamiliarity with the equipment. Medical equipment comes with a standard one year warranty precisely to cover this period. This is why it is important to ensure that the warranty period only starts when the equipment starts to be used. At the end of its life time, the failure rate of the equipment will increase again. At some point, the failure rate and the associated cost of repair, become so high that it is not economically viable to keep repairing the equipment. This is when we say that a device has reached its end of life and it should be decommissioned.



The 'bathtub' curve describes the failure rate of medical equipment over its life time.

Repair of broken equipment or Corrective Maintenance (CM) makes good economic sense if the cost of repair is smaller than the remaining value of the equipment. For example, if our 12,000 USD device with an expected life time of 10 years is 5 years old, its remaining value is 6,000 USD (with linear depreciation). So if the cost to repair this device is 600 USD, it is economically worthwhile to do that, provided that it is then will function without further repair for at least a half year.

Traditionally in equipment maintenance, a device was used until a break-down occurred. At that point it was decided whether it was worthwhile to repair it, depending on the cost of repair and the expected remaining lifetime. More recently, international experience has demonstrated that there is a better way to maintain medical equipment: through the use of Preventive Maintenance (PM).

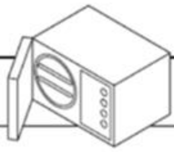
With PM, a device is checked regularly, before it is broken. PM also includes prescribed daily and weekly care by equipment (clinical) users. PM has shown to give the following benefits:

- The total cost of maintenance over the lifetime of the equipment is lower.
- The medical equipment (ME) Uptime, the time that equipment is functional, is higher. This is because PM is planned while CM (breakdown) comes unexpectedly, leading to delays in manpower allocation and the procurement of spare parts.
- The expected life time of equipment is a factor of 2 longer.
- Operational patient care in the hospital runs more smoothly, because PM can be planned and clinical procedures can be scheduled in line with it. Unexpected equipment breakdowns and associated CM cause inefficiencies for both hospital personnel and patients who need to come back for their clinical procedure another time.
- The safety of using the equipment for patients and healthcare workers is higher, since (unwanted) changes in the function of the equipment will be detected and corrected early during PM.

For these reasons, Biomedical Engineering professionals around the world consider the execution of a Preventive Maintenance program in every hospital a must.

A major financial benefit of a good maintenance program, including PM, is illustrated in the Table below. It shows that the expected increase in life time of a device through good maintenance is enough to justify the cost of maintenance.

BOX 11: The Financial Benefit of Maintaining Equipment



Example 1: An electrically operated autoclave, horizontal bench-top model

With maintenance	Without maintenance	Effect
• Average lifetime is 12 years if properly maintained	• Obsolete after 5 years according to a study by the German Technical Cooperation Agency (GTZ)[1]	• Without maintenance, you lose 7 years of potential life of the equipment.
• One new autoclave is required after 12 years = US$3,500	• 2.4 new autoclaves required over that 12 year period = US$8,400	• Maintenance allows you to postpone reinvestment for 7 years. Without maintenance the additional autoclaves you require over that period = US$4,900.
• Maintenance of medical equipment (such as this model with sophisticated electronic controls) requires an average of 5% of purchase price per year = US$2,100 over 12 years	• No cost incurred for maintenance	• Maintenance costs are less than the cost of the additional replacement autoclaves required if no maintenance is carried out.
• Total cost = US$5,600	• Total cost = US$8,400	• Even when funding maintenance, you still obtain considerable economic benefit = US$ 2,800.

Table[11] demonstrating that the expected increase in life time of a device through good maintenance is more than enough to justify the cost of maintenance.

Next to good maintenance, also the intrinsic quality of medical equipment has a major impact on failure rates and life time of equipment. The failure rate of low quality equipment is much higher

[11] How to Manage' Series for Healthcare Technology: Ziken International (Consultants) Ltd, 2005. Guide 1, page 32

than that of high quality equipment and its lifetime is shorter. Roughly, high quality equipment has twice the life time of low quality equipment. See Table below.

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Equipment type	Lifetime in years			
	Poor quality makes		Good quality makes	
	Poorly maintained	Well maintained	Poorly maintained	Well maintained
Anaesthetic machine (Boyles)	2 – 5	5 – 10	5 – 10	10 – 15
Centrifuge	3 – 4	7 – 8	6 – 9	10 – 12
Microscope	3 – 6	5 – 10	6 – 10	10 – 20
Oven, hot air (laboratory)	2 – 6	5 – 8	6 – 10	10 – 15
Refrigerator (electrical)	3 – 5	5 – 8	5 – 8	10 – 15
Refrigerator (kerosene)	4	4 – 8	5 – 10	10 – 17
Sphygmomanometer (aneroid)	1 – 3	2 – 3	2 – 5	5 – 10
Sphygmomanometer (mercury)	1 – 2	3 – 5	3 - 5	8 – 10
Sterilizer, bench-top (horizontal)	3 – 5	5 – 8	6 – 10	10 – 14
Sterilizer, floor-standing (vertical)	3 – 6	5 – 12	8	14 – 15
Suction pump (electrical)	1 – 3	5 – 7	5 – 8	10 – 15

Table[12] demonstrating that both high and low quality equipment benefits enormously from good maintenance.

Whether procuring high or lower quality equipment, it is true in both cases that good maintenance will prolong the life time of equipment by a factor of almost 2.

High Income countries do not procure low quality equipment because the cost of disturbances to hospital procedures – in wasted man hours - is much higher than the benefit from the low procurement price. Lower & Middle Income Countries work with lower salaries and a greater tolerance for disruption of patient flows. They may be more attracted to low procurement prices, because of their limited financial means and the high unfulfilled demand for equipment from so many hospitals.

Cost of Maintenance

Internationally, the cost of maintenance of medical equipment is expressed by the 'Cost of Service Ratio (COSR)'. This is defined as the yearly cost of providing maintenance divided by the initial procurement cost of the equipment. The COSR can be calculated at different levels: hospital, district, province, etc.

[12] How to Manage' Series for Healthcare Technology: Ziken International (Consultants) Ltd, 2005. Guide 2, page 269.

$$\text{COSR} = \frac{\text{the total annual cost of maintenance}}{\text{the initial cost of medical equipment in the inventory}}$$

The total *annual cost of maintenance* includes labor hours of BioMedical Engineering Technologists: BMET's, spare parts and external ('3rd party') maintenance contracts. It assumes that workshops, tools and test equipment are available. The *initial cost of medical equipment* is the total amount of money that it would take to procure all equipment in the region.

In the US healthcare system, normal values of COSR have been reported to be 4.5% – 6.0%[13].The AAMI[14] (Association for Advancement of Medical Instrumentation) has listed the national average for COSR at 5.25% several years ago.

The COSR consists of different elements:

- For medical equipment that is maintained by a specialized 3rd party service provider, the COSR in the US is in the order of 6% - 10%.
- For equipment that is maintained by 'In House' technicians, the COSR is in the order of 4%-6%.

Note that for complex medical equipment the outsourcing of maintenance to a 3rd party (private) maintenance provider is usually preferred. Service training for such equipment is so costly that it can only be justified if a trained technician works on the maintenance of a high number of systems. Usually a hospital or region has too low numbers of the same equipment to justify specialized training of a local technician.

ME Maintenance in Zambia

In Zambia, we would expect that the norms for COSR are lower than in the US, related to the lower local salary costs. On the other hand, the procurement costs of equipment and spare parts is often lower and the failure rate is higher (lower quality, older equipment). A rough estimate would be that 3% COSR would be needed for in house maintenance and 5% for 3rd party service.

Most of the high-end, complex equipment in Zambia is under contract by service providers. This is e.g. the case for Imaging equipment, including CT, X-ray and Ultrasound systems. The actual COSR here appears to be higher than the 5% target discussed above. This high price may in part reflect the cost of maintaining old equipment which should be considered for decommissioning and replacement.

For some of the other high end equipment, third party maintenance is procured on an ad hoc basis ('paid repair') rather than as an ongoing service contract. This is usually done by individual hospitals who have an urgent problem with an indispensable medical device. In general, 'paid repair' is a costly approach leading to high downtime due to the lack of PM and poor response times of the service providers.

[13] Ted Cohen: 'AAMI's Benchmarking Solution: Analysis of Cost of Service Ratio and Other Metrics'. Biomedical Instrumentation & Technology, page 347, July/August 2010 http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.610.1012&rep=rep1&type=pdf

[14] www.aami.org

Another form of third party maintenance is applied to sophisticated laboratory Analysers (e.g. chemistry analysers and haematology analysers) in Medical Laboratories. The procurement prices of such equipment as well as the associated maintenance costs are low compared to the use of consumables (chemical reagents) in these systems. Therefore, there is usually an integral contract in place that covers all costs, including consumables, initial procurement and maintenance costs. The commercial providers of this type of equipment have a high economic interest to keep the equipment functional, in order to sustain the turnover of their reagents. In general, these companies provide reasonable service, including PM.

For all other equipment, maintenance is provided by 'In House' employees. Currently, in Level I Hospitals, such maintenance is often a side job of the employee who takes care of the electrical systems in the hospital. This person has usually not received training for medical equipment and does not fully comprehend its function and its user requirements. As a consequence, in many district hospitals the medical equipment is not well cared for and preventive maintenance and user training are not done.

In level II and III hospitals, usually one or more employees are dedicated to Medical Equipment maintenance. Most of these workers have had limited specialized training in medical equipment maintenance. Besides, the number of such workers in these hospitals is low compared to the amount of medical equipment present. A rule of thumb here is that 1 BMET per 100 units of equipment is adequate.

Experience obtained thus far indicates that on average 30% of all medical equipment in government hospitals is not functional. Anecdotal evidence suggests that Mining and some other Private hospitals run preventive maintenance programs and are doing significantly better in this respect.