

Medical Equipment Library Design: Revealing Issues and Best Practice Using DiCoT

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ABSTRACT

Medical Equipment Libraries (MELs) are a relatively new function for hospitals in the UK, which aim to save money and make medical practice safer. They centralize the management, maintenance and purchasing of medical equipment. They are being embraced and developed by some hospitals, and considered by others. Hence, there is a growing need to understand MEL practice and design. This paper compares three MELs through interviews and observations of everyday practice using DiCoT (Distributed Cognition for Teamwork) as a method for multisite comparison. This is a novel use of the method that reveals general issues and best practices across contexts. Our results complement the little formal information that is available on MELs, and explores the workings of the library as a socio-technical system. As far as we are aware no empirical studies have been published in this area. We conclude with design opportunities and requirements for MELs, and propose DiCoT as an effective way to compare socio-technical systems, including revealing issues and best practices in other clinical contexts more broadly.

Categories and Subject Descriptors

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms

Management, Documentation, Performance, Design, Human Factors, Standardization.

Keywords

Medical Equipment Libraries, Distributed Cognition

1. INTRODUCTION

There is growing interest in the design and use of medical equipment libraries (MELs) in the UK. At director-level policy makers are concerned if there is sufficient benefit (in terms of financial savings, improved performance and safety) against the set-up and running costs of the library. More operationally managers need insight into how these libraries are organized and operate at a shop-floor level. This includes managers that are tasked with developing a MEL from scratch, or those reflecting on ways to improve their current practice. Understanding the mechanics of MEL as a socio-technical system has direct relevance for HCI, e.g. for identifying design opportunity, requirements and to make sure that designers are informed of current practices so new designs do not introduce new problems.

In this study we investigated MELs in terms of what they do, how they work, current practices and how these have evolved over time. The primary objective of this paper is to understand MEL practice, identify recommendations for improvement and to

inform best practice. Our motivation for this research emerged from CHI+MED (Computer-Human Interaction for Medical Devices). CHI+MED is a large UK-based research project that aims to improve the usability and safety of interactive medical devices, such as infusion pumps. MELs have evolved from efforts to make medical device use safer by centralizing and standardizing device models used in hospitals. Distributed Cognition for Teamwork (DiCoT) was used as the research method for this study [2]. DiCoT has been used in single site studies but not for multisite comparisons. Hence a secondary objective was to explore its potential to compare multiple sites to reveal general issues and best practice. This novel use of the method has wider relevance for comparing other clinical contexts to help extrapolate and foster best practices.

2. BACKGROUND

2.1 Medical Equipment Libraries

A medical equipment library is a facility in a hospital that coordinates and manages the use of medical devices. More importantly, it centralizes high-risk and heavily utilized equipment in order to ensure patient safety. Infusion pumps fall into this category, because their models can vary greatly, are used frequently by many wards and are involved in many adverse incidents. It was more than a decade ago when hospitals understood the benefits of managing safety critical devices in a centralized place. Besides the practicality of having these devices ready for use and at hand in an accessible storage area, MEL's facilitated the standardization of high-risk devices. In the UK, the number and variety of infusion devices has been reduced in many hospitals in response to National Patient Safety Agency (NPSA) advice. This reduction has also made training easier, resulted in cost savings and improved patient safety.

Other than infusion pumps, a MEL can be stocked with various types of medical equipment, like patient monitors, ECG recorders, incubators, blood gas analyzers, nerve stimulators, dynamic mattresses, hospital beds and more. MEL staff vary but can include nurses, technicians and device trainers. Equipment coordinators are responsible for a wide range of services, which also varies from MEL to MEL. These tasks can include: managing storage and inventories; managing loan requests, delivery and collection; record keeping; calibration, repairs and maintenance; cleaning and decontamination; training on medical equipment; adverse incident reporting; disposal; selection, procurement and acceptance testing; and dealing with service contracting parties. This covers a broad range of complex activities that need to function well to provide a critical service to hospital wards. Given the relatively new nature of these services it was not clear what sort of technological support was already in place, what may be

needed or where the socio-technical challenges lie. We return to these issues at the end of this paper.

To highlight the potential benefits of MELs one MEL manager reported the improved management of dynamic mattresses as a success case. Dynamic mattresses are needed to relieve the pressure on the skin of patients as they lay in bed either because their skin is particularly sensitive or if they have been bedridden for a long period of time, unlike static mattresses the surface of the mattress moves relieving pressure points. For the hospital in question these mattresses were rented at a considerable daily cost by wards that might need them. Research by staff identified that there were many dynamic mattresses in different areas across the hospital, many were in a poor state of repair and others were stored and not used whilst still costing the hospital daily. The introduction of a MEL meant that this resource could be centrally managed so that the mattresses were all functioning properly, and the hospital was not paying expensive loan fees for mattresses that were only stored in closets.

2.2 DiCoT

To study the workings of MELs we took a socio-technical systems perspective. Here one pays special attention to the integrative nature of humans, devices, tools and the organization of the environment which all impact on the performance of the system.

One theoretical perspective that facilitates such analysis is Distributed Cognition (DCog). DCog is an approach to understand cognitive phenomena across various agents (human agents, computerized agents as well as non-technological artifacts) and their internal and external representational states. It looks at how all components are socially and cognitively organized in order to achieve a goal in collaboration [14; 12]. In other words, DCog is concerned with understanding the interactions between people and technologies and what people do within whole environments and how they coordinate their activities in them [5]. One of the key things is how information is represented and how these representations change over time as they move across agents.

DCog originates from cognitive and social sciences and cognitive anthropology [14] and distinguishes itself by claiming that cognition is not just in the head, but in the world [11]. Hutchins [6] coined this idea as “cognition in the wild” by describing in detail how the USS Palau, a US navy ship, is maneuvered into its landing position. This classic example of DCog highlights how different crewmembers transform and propagate different information, with the use of tools and artifacts, to collectively navigate and control the ship. Perry [12] states that at no point in this process it can be said that a single person navigated the ship.

To facilitate the application of DCog theory in a structured manner we use DiCoT [2]. This method draws on ideas of Contextual Inquiry [1] as it separates the main areas of interest into five interdependent models to gather and structure data:

1. The Information Flow Model concentrates on workflows, the people involved and how they communicate. It tracks how information is processed from one stage to another.
2. The Physical Model shows the physical layout of a workplace and how work is physically organized. It is concerned with spatial factors that influence (shape, empower or limit) the performance of the system and its components.

3. The Artifact Model records things that are created, used, modified and become artifacts of work. It considers how these are designed to support cognition.
4. The Social Model informs about the people involved, their roles and responsibilities. It gives insight into experiences, learning and transfer of knowledge.
5. The Evolutionary Model investigates how the cognitive system has evolved over time. It detects why things are done in certain ways.

Each model has associated principles that provide heuristics for applying DCog theory [e.g. see 2]. We refer to these principles where appropriate in the analysis in Section 4

This study proposed to use DiCoT in a novel way. Previous studies have focused on one site for data gathering. A single ambulance control room was investigated by Furniss and Blandford [2], a healthcare facility by McKnight and Doherty [7] and Sharp et al. [16] focus on the artifacts used by an agile XP team. More recently, single site studies in the healthcare sector have been carried out [e.g. 4, 13]. Our investigation of MELs differs because we analyze data from three separate sites and incorporate views from practitioners at several other locations.

3. METHOD

Over three intensive weeks of data collection three MELs were visited as well as eight dedicated interviews on the nature and organization of MELs. Ethical clearance was granted by the university, the participating NHS sites granted clearances, and participants gave informed consent to take part in this study.

In total, six visits to the MELs were undertaken. One MEL was designated our primary site of study because it was easily accessible and represented a large and fully functioning MEL (we refer to this as MEL1). This primary site had four visits, with the remaining two visits carried out at the supporting sites for validation and contrast (we refer to these sites as MEL2 and MEL3). Each observation session lasted about 1-4 hours, including note taking, sketching, taking photographs, informal interviews and interposed questions.

Following the principle of theoretical sampling our observation times were chosen to give a richer understanding of the context, i.e. data collection times were not random or for convenience but chosen for their potential to shed light on how the context operates at different times of the day and at different times in the week. For example, we expected to find out about different work processes at the beginning of workday and different kinds of work were anticipated at weekends also.

The five models of DiCoT were not only used to analyze the raw data from field study observations but were used to shape the data collection. More specifically, whilst in the field we took notes on what was happening, what artifacts were used, how they changed, how they moved around the space and also what communication took place between staff over which channels.

Three interviews with staff in management roles were conducted at cooperating facilities, each of which lasted about an hour. The interviews' purpose was to gain general knowledge about MELs and get more detailed information about the functions, responsibilities, social and evolutionary developments. Importantly, managers were able to validate findings and understandings that were emerging from the observations.

In addition to face-to-face interviews, five semi-structured telephone interviews with members of the Medical Device

Trainers Association (MDTA) and Electro-Biomedical Engineering (EBME) were conducted. Each telephone interview lasted between 15 and 60 minutes and was audio-recorded for transcription and further analysis. The interviewees included managers, equipment coordinators and medical device trainers who were located in MELs across the UK. Three of five interviewees were involved in setting up some of the first MELs in the UK.

As expected, both observations and interviews brought rich amounts of data that fed into DiCoT's five models. All field notes and transcribed data were color-coded and annotated in order to identify relations to each of the models. Due to the nature of the analysis, interview data was the main source for the Social and the Evolutionary Model, whereas sketches, photographs and notes from observations mainly informed the Physical, the Information Flow and the Artifact Model.

In order to validate the findings and recommendations from our analysis, practitioners were invited to give feedback on a draft report. We return to the results of this validation stage in the discussion section.

4. RESULTS/ANALYSIS

We present the results of our study through the five models of DiCoT and its associated principles (*in bold italics*). In each of these models we identify examples of best practice and issues of concern.

4.1 The Evolutionary Model

The concept of MELs in NHS trusts emerged about 15 years ago when medical engineering departments realized a need for better management of infusion devices. In cooperation with the first visionary thinkers who initiated the introduction of centralized, staffed MELs, the NPSA (National Patient Safety Agency), MHRA (Medicines and Healthcare Products Regulatory Agency) and NAO (National Audit Office) developed recommendations and guidelines for setting up and operating medical device management systems [8; 9; 10]. To provide the historical context: a safety code for the design and construction of electro-medical apparatus was set as a first national standard for the equipment itself. A decade later people realized that there was more to safe device management than their design and use, and so the maintenance and management of medical equipment was considered by NHS hospitals. From then on, various documents (e.g. HTM 8, British Standard BS 5724 part 1, HEI 95 later IEC 60601-1, MDA DB9801, DB 9801, DB 2000(02)) were released, replaced, withdrawn, overwritten until finally, in 2006, they were superseded by the MHRA's Device Bulletin DB2006(05) – "Managing Medical Devices – Guidance for healthcare and social services organizations". This document considers the purchasing, deployment, maintenance, repair and disposal of medical devices. It also contains guidance on equipment library policy development and compliance. This development of documents, processes and practices comprise part of the *cultural heritage* of MELs, i.e. the expertise and structure that has evolved year on year and which will be inherited by and built upon by future generations [2, p1179].

4.1.1 Best practice examples

4.1.1.1 Standardization and training

One of the major reasons why MELs are so important is the overall goal of achieving standardization. This means the reduction of different makes and models of medical devices and the added need for wards to consult with MEL and EBME when

wanting to purchase equipment. It has been recognized that all sources reported highly similar procedures regarding procurement of equipment. Many MELs initiated the disposal of all obsolete and variant equipment and the acquisition of new devices. Generally, several manufacturers are invited to present their products. Senior nurses from wards and departments and qualified technical staff evaluate the equipment in terms of usability, robustness and acceptance. Initial purchase costs are then compared against the cost of consumables (tubes, leads, plastics, etc.) before a final decision is made. The procurement process then continues with sufficient training on the new equipment. Many companies send device trainers along with equipment, but some hospitals employ their own medical device trainers (e.g. MEL1) or someone who is qualified to identify training needs (e.g. MEL2). The trainers make sure that nursing staff receive appropriate training during the initiation phase – to help initiate the development of their *expert coupling* with the device [2, p1180]. Appropriate levels of training can be identified by a classification scheme. For example, MEL3 categorizes equipment between 1 and 5, where 1 indicates any harmless equipment that is near patients and 5 indicates high-risk devices like volumetric infusion pumps. MEL3 makes sure that 80% of staff of each ward is properly trained. Other interviewees reported a well-known system that uses a traffic light scheme. Both, staff and equipment are categorized as red, yellow or green. Red indicates high-risk devices and can only be used by staff that have been trained accordingly, i.e. to red-level training. Training is offered and required frequently to refresh the users and familiarize them with software updates.

4.1.2 Issues of concern

4.1.2.1 Pressure relieving equipment

Pressure relieving equipment needs to be returned promptly by staff to avoid unnecessary rental costs. MELs try different strategies to keep the loan costs of dynamic mattresses at a minimum. Strategies include the management of pressure relieving equipment either fully carried out by the MEL or in conjunction with contracting parties (equipment suppliers) as in MEL1. Dynamic mattresses can be hired or purchased, where both strategies have their pros and cons. To this day, most MELs hire the equipment and control their usage. Policies force wards and departments as well as equipment coordinators to not overly exceed loan times. This is to avoid dynamic mattresses sitting somewhere, not being used but still on expensive loan time. Such a case has been observed in MEL1 where nursing staff are instructed to make a collection request as soon as a mattress is no longer in use to ensure cost efficiency.

4.1.2.2 Device tracking

Device tracking is a big issue as property is lost and is not accounted for. More effort could go in to developing systems to improve the *situation awareness* of the system in terms of the location of the devices, who has responsibility and what state they are in. RFID technology has been experimented with but is currently considered costly and impractical by our participants:

No current example of developed device tracking could be found in either of the three sites. Although it is known and recognized that equipment goes missing, more effort could be put into tackling this issue. MELs simply accept that this can happen. Sometimes, equipment is lost for several months or permanently. Devices travel between wards when patients are transferred, patient monitors or some types of pumps leave the hospital with the patient and some pieces of equipment simply disappear in the wards' closets and drawers for various reasons, which was part of

the rationale for MELs in the first place. The general policy is to reconstruct who loaned the equipment last and charge the respective ward or department with the replacement. However, inventories are rarely carried out. MEL3 was involved in a trial run for RFID tagging. The MEL was supplied with 25 RFID sensors, which were attached to the outside of the devices. After the project finished, the management was not convinced of the additional value RFID tagging brings to the MEL. Although the RFID system provided an equipment location accuracy of 5 meters and an accessible visual representation, equipment coordinators still preferred the T-card system for locating equipment (we describe this further in Section 4.4). Also, the RFID tags are of notable size and an awkward blob attached to a device, which complicated cleaning because it required care to not detach it. This system with only a small number of tagged devices and access points that were not spread across all hospital wings may have influenced its efficiency. According to the management of MEL3, RFID tagging would be worth considering once the system has been developed further. Our participants believed that manufacturers plan on implanting RFID tags inside medical devices. Besides device tracking, such a system can facilitate software updates, alerts for service or incidents and more. For now, this technology is not favored by most hospitals due to cost and the perceived impracticality.

4.1.2.3 Sharing best practice

Best practice sharing between practitioners is not yet carried out well. Many official organizations (e.g. MHRA) do their best to inform practitioners through guidelines, alerts, reports, studies and conferences. However, these more formalized abstractions can seem detached from practitioners' perspectives on the shop-floor. EBME has set up a forum for practitioners that enable them to discuss their practices and share their experience. Such a platform is a first step towards best practice sharing. However, it would be beneficial to make these examples available in a more official manner to support knowledge exchange and *cultural heritage*. As mentioned in Section 4.2.1, setting up MELs only became more widely practice around 2006. It seems timely to reflect on experiences and lessons learnt for setting up and optimizing MEL practice. This paper begins to distil and make MEL issues and best practice clearer.

4.2 The Information Flow Model

The high-level function of a MEL is to provide wards and departments with fit-for-service equipment and to deliver it in a timely manner. This is illustrated in an input-output diagram shown in Figure 1. Fit-for-service equipment is stored in a safe place and issued upon request. Records are kept to keep track of the location, condition, availability and usage of equipment.

4.2.1 Best practice examples

4.2.1.1 Unique identification of equipment

Unique identification of equipment is a feature that eases the communication between experienced and uninformed staff, e.g. porters are not medically trained but might be asked to collect medical equipment, as observed in MELs 2 and 3. This helps control unwanted *information transformation* as it minimizes miscommunication and misunderstandings when wards or departments ask for a device when different types exist.

Through habituation in their own contexts nursing staff have previously requested "IVAC pumps" from MEL2, which only indicates the manufacturer of the pump. A request like this does

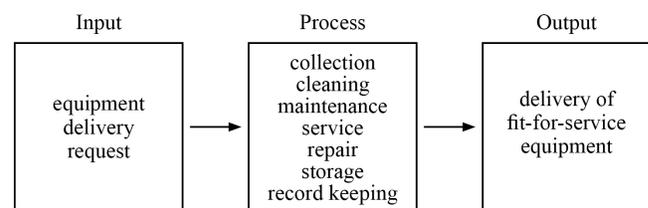


Figure 1: Input-output diagram of a MEL

not give a precise indication of what type of pump is needed. Therefore, communication through unique identifiers is quicker and more accurate. This also makes the labeling of equipment and shelves much clearer. Untrained and inexperienced staff (e.g. porters) do not need to be challenged with remembering models and makes, which eliminates false identification and delivery. One good example of uniquely identifying equipment is the introduction of short combinations of letters and numbers that stand for complicated equipment names and types. For example, "D01" stands for a specific model of a feeding pump, whereas "D04" represents a suction pump. MEL2 handed out information sheets to all the wards where these unique identifiers were used. The original make, model and a photograph of the device were listed on this.

4.2.1.2 Monthly staff meetings

MELs have a wide variety of users across the hospital. Monthly staff meetings open communication channels between these parties so issues can be heard and addressed. A useful approach to optimize the work processes of a MEL, which is currently practiced by MEL2, is to bring together representatives of all participating parties to discuss issues, proposals and needs. These representatives can include all wards and departments, workshop technicians, equipment coordinators and their managers and medical device trainers. These *information hubs* provide a place for considering different needs and perspectives so the MEL's service can be improved. Importantly, staff need to be happy with the MEL service and trust it; otherwise they might start hoarding equipment locally, which would lead the system to breakdown.

4.2.1.3 Equipment usage reports

The centralized management of devices through MELs allows better monitoring of equipment usage. A best practice example of monitoring involved a library producing monthly usage reports. We identified this from our telephone interview data but it was not practiced in either MEL1, 2, or 3. These reports can be generated easily from the database, which means it is minimal effort but high value. They contain information about what equipment is used a lot, what kind of equipment is seldom requested and if there are any shortages. Equipment managers can thus observe over months if there are any needs for the acquisition of new equipment or if some other issue needs investigating further. For example, equipment may not be used because of usability issues or other reasons. Furthermore, such reports could also contain information on how long equipment stays on loan and what devices have a high throughput. In practice, equipment coordinators know these things from experience, but informal perceptions do not always match more formal records.

4.2.2 Issues of concern

4.2.2.1 Equipment collection

Equipment collection is sometimes done in a rather ineffective way. In the three MELs we visited, it is common practice to do two equipment collection rounds on an average per day. One is at the start of the morning to collect equipment that has been used

overnight. The other is generally in the afternoon to collect equipment that is used during the day as patients come and go and equipment is no longer needed. Unused equipment is collected at an assembly point, where equipment coordinators arrive with their trolleys and take it away for cleaning and maintenance. However, MEL1 handles collection of equipment differently. Wards and departments notify the MEL whenever they are ready to release equipment, which means that these processes are based on **behavioral trigger factors** such as phone calls, verbal requests or other forms of formal or informal requests. Informal requests are transformed into formal requests as soon as the according paperwork is completed or a database entry is created. DiCoT calls this **information transformation**, which occurs when the representation of information (informal or formal verbal request) changes (filled-in request form or database entry). For collection requests, equipment librarians effectively act as an **information buffer** as they hold back requests and complete them at more appropriate time. Although equipment librarians mostly group between 2-5 collection requests together before going to collect them it seems to be inefficient. The journeys are time consuming and other work stays on hold. An upside of this practice is that availability of equipment is guaranteed and dirty equipment never stays for long at the wards' assembly points. MELs need to consider these trade-offs: e.g. whether to have scheduled collections, when and how many, and whether to have a more reactionary collection service.

4.3 The Physical Model

There are two major factors in terms of the physical organization of a MEL: the allocation and use of the space available within the MEL, and the location of the MEL in relation to the wards and departments of the hospital. Centralized MELs are relatively young facilities in the history of hospitals. Therefore, the space that was allocated to them tends to be rather small. Librarians and their managers have developed **arrangements of equipment**, like shelves, desks and storage areas in relation to the room and how each of these are organized themselves. Figure 2 demonstrates how MEL1 organizes its **space and cognition**: here the physical arrangement of the space impacts the cognitive work of the individuals, tools and artifacts that interact within it. Office work and repairs are handled in their dedicated space. Clean and fit-for-service equipment is stored on the designated shelves, but the cleaning of equipment involves dirty equipment coming in, temporarily being stored, then cleaned and finally properly stored on the shelves. The fact that dirty, sometimes contaminated, broken or faulty equipment and clean, fit-for-service equipment are dealt with in the same wider space requires communication and **situation awareness**. Ideally, clean and dirty equipment would be stored physically far from each other in designated clean or dirty areas. Another important factor that influences the impact a MEL has on the safety of medical devices is the location of the equipment library and its distance to hospital wards, which influences the risk of damage during transport as well as manual handling of large items.

4.3.1 Best practice examples

4.3.1.1 Central location of MEL

During the investigation it was found that almost all MELs are located at far ends or lower ground floors. The Physical Model highlights the benefits that a more centralized facility has. This includes better and safer management of equipment as it spends less time in transit, more efficient time management for people travelling to and from the MEL, and finally greater presence, and awareness of the service.

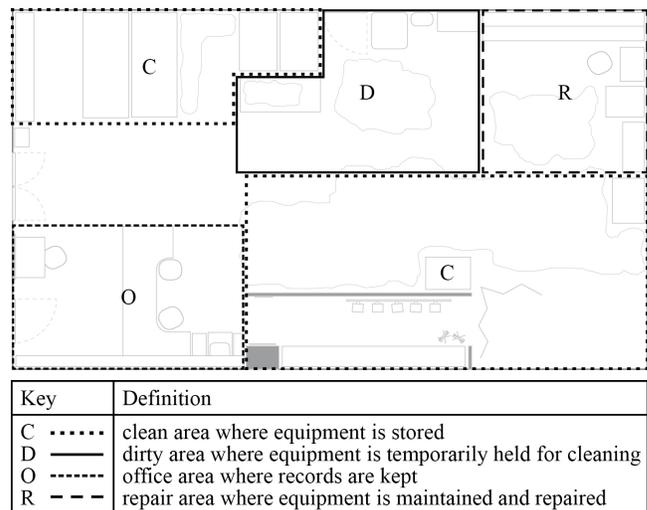


Figure 2: Layout of MEL 1

4.3.2 Issues of concern

4.3.2.1 Labeling of storage areas

'Unique identification of equipment' was mentioned before as a best practice example in Section 4.2.1.1. In terms of shelving it has been observed that not all MELs place prominent labels on the shelves to indicate what type of equipment is stored there. Normally, this is not an issue for experienced equipment coordinators. But temporary staff or novices (especially porters who are not necessarily familiar with medical devices) may have difficulties finding the right piece of equipment. There may also be times when the MEL is unmanned and staff unfamiliar with its layout need to find their way around the space.

4.3.2.2 Lighting conditions

Most equipment libraries are furnished with a workbench where repairs are carried out. The nature of such work involves the fiddling around with small, fine parts and therefore requires good lighting conditions. Workbenches are placed against the wall, which means that the technician blocks the light coming from the ceiling with their back. We found desk lamps on some workbenches but these were not common.

4.4 The Artifact Model

MELs differ in the amount and the importance of artifacts used during normal work processes. The three most important, **mediating artifacts** used in a functioning MEL are the equipment loan request form, the T-card system and temporary lists and notes. These artifacts aid the **coordination of resources**. As mentioned previously, all MELs work with equipment loan request form in paper form or as a database form for entry. The information captured is key to determine which equipment is where and for how long. A far more visual representation of this information is provided by the T-card system, which allows a quick overview of the quantity and distribution of equipment across wards while serving as a backup in case the computer system is down. Especially in MEL1, temporary lists and notes play a major role when handing over shifts or transforming phone requests for pick up or delivery into formal loan requests. This shows people **creating external scaffolding** to support their cognitive tasks [2, p1179].

4.4.1 Best practice examples

4.4.1.1 Reduced paperwork

It is common practice for equipment librarians to fill in paper loan requests in order to capture all required details for an equipment request. MEL1 has a paperwork-heavy procedure: for example when capturing equipment requests via phone handwritten notes are transferred into forms to then be entered into the computer system. Only MEL3 does not use paper forms, but enters all information directly into the database. On the one hand, the redundancy of information when entered on paper and into the database serves as a backup. On the other hand, it is inefficient to process each request twice. A good IT infrastructure ensures backup and reduces redundant paperwork.

4.4.1.2 Color-coded T-card system

A point has been made about redundant paperwork and backup. A backup system that also aids database entry and device tracking is the T-card system that is in use by some equipment libraries, but not MEL1. It consists of T-cards and a T-card panel with slots for these cards. The cards contain the asset number, the name of the equipment, a dedicated color for this type of equipment and in some cases barcodes. These barcodes enable scanning of the asset number. The panel is structured in a way so it represents all wards and departments that interact with the MEL. In case a ward name changes, it can easily be replaced. T-cards are allocated to the wards depending on which devices are currently loaned out by them. The panel is big enough to be able to host all wards and departments of the hospital and to allow more than enough slots for all the equipment T-cards a ward can possibly occupy.

The T-card system's value lies in a backup system that enables equipment coordinators to grasp the distribution and availability of equipment at a glance without having to browse the shelves or search the database. This abstract representation facilitates a better *situation awareness* of what devices are where. This is further facilitated by mounting the panel onto the wall where it can be seen at all times (this requirement crosses over with the concerns of the Physical Model). An additional informal feature was discovered during observation in MEL3: paperclips (see circled area in Figure 3). At the end of the shift, an equipment librarian places a paperclip on the last T-card in each row (where a row represents a ward or department section on the panel). Then, at the beginning of the next shift, s/he can easily see what equipment has been taken out during out-of-hours by porters. These T-cards are placed below the one with the paperclip. In order to remind porters to put the cards in the right slot on the panel, the individual T-cards are directly attached to the devices where they can hardly be missed. Moreover, in MEL3, the T-card panel cannot be overlooked, because it is placed directly next to the door. Whenever a person removes equipment from the library, the panel serves as a reminder (or *behavior trigger*) to detach the T-card from the device and put it in the right slot on the panel.

4.5 The Social Model

MELs are small organizations in terms of their *social structure*. However, their relation to many other parts of the hospital reveals how integrative MELs are. They act as hubs between patient's needs (e.g. safe and timely treatment using fit-for-use equipment), nursing staff's needs (e.g. enabling their work and training), workshop's responsibilities (e.g. by dealing with faulty or broken equipment) and those involved in management and procurement of devices. In return, MELs rely on all these parties and some others (e.g. porters) to function. Comparing the *social structure and goal structure* [2, p1180] reveals that some goals are shared and others are not. The overall *goal* of all parties involved is

available fit-for-service equipment. However, not everyone holds the same value for other goals such as returning and cleaning equipment, and keeping administrative systems up-to-date.

4.5.1 Best practice examples

4.5.1.1 Out-of-hours handling

Out-of-hours are handled differently in the MELs we observed. There is a trade-off to be made between continued service and staffing costs, which might depend on how busy the MEL is. However, we have observed positive strategies to alleviate this problem. For example, MELs 2 and 3 allow access to their premises during nights and weekends. This can cause various problems, one of which is record keeping. Porters, nursing staff or whoever has access to the MEL are authorized to loan equipment whenever needed. However, this authorization includes filling in loan request forms and giving all details required. Due to a lack of knowledge, willingness or time of hospital staff, it is often the case that this paperwork is not filled in sufficiently. Important information, for example the ward name or the name of the person who took the equipment, is missing or other parts of the forms are incomplete. On rare occasion, no record is kept at all. These incidents encourage MELs to install CCTV or swipe card readers and to dedicate unnecessarily high amounts of their time to track down devices. Another problem is that during out-of-hours, the shelves of the MEL get emptier and emptier, whereas the assembly points on the wards fill up with unused equipment. This is especially critical over public holidays that leave the MEL unmanned for more than 2 days. One best practice example of handling out-of-hours times is MEL1, which also operates on weekends. Weekend shifts of about 6 hours per day where all necessary tasks are performed by only one equipment coordinator ensures that the wards and departments are supplied with the equipment they need in an appropriate condition. During this period the MEL keeps non-urgent tasks (e.g., tracking down equipment, dealing with incomplete paperwork and accumulated cleaning and maintenance tasks) down to a minimum. For night hours, MEL1 allows access to a storage room that is separate from the actual equipment library were high-use equipment like infusion devices are stored. Every ward and department has access to this out-of-hours store and is responsible for filling in the appropriate paperwork themselves. The operation of such a storage room requires daily checking, record keeping and restocking, but it minimizes the risk of unauthorized staff messing around with the actual MEL and its organization.



Figure 3: T-card panel with paperclip

4.5.2 Issues of concern

4.5.2.1 Socially clean equipment and collections

Ward staff are responsible for making sure that the equipment that is due to be collected by MEL is socially clean, has a sticker attached to it to identify it for collection and is gathered in a collection area. However, it was reported by MEL1 that ward areas did not always fulfill their responsibilities. For example, most policies obligate wards and departments to return equipment in a 'socially clean' condition. This means, that any obvious soiling has been removed, and the equipment is wiped and is not infectious. However, equipment that is awaiting collection is not always socially clean. Furthermore, nursing staff are asked to attach "I-am-clean" labels to socially clean equipment, which can also be neglected. Currently, it is the MELs duty to deal with this on going issue. Regardless of whether the equipment is socially clean, equipment coordinators will thoroughly clean and decontaminate any equipment they collected from the wards.

4.5.2.2 Health and safety regulations

Health and safety regulations are not always followed by staff. For example, it has been observed that not all equipment librarians use gloves when handling dirty equipment. Better education about the risks (e.g. infection) and a more strict policy should increase awareness and acceptance. There may also be workflow issues that need to be addressed here so clinical handling that needs to be clean can be separated from non-clinical procedures such as administrative tasks that can be more relaxed in terms of infection control.

4.6 Results Summary

To provide an overview of the points made in section 4.5 we perform a claims analysis [15] which will show the main positive and negative factors to be considered: Table 1 and Table 2 present the claims analysis for the best practice examples and for the issues of concern respectively, across all the models.

5. DISCUSSION

This paper had two complementary objectives: the first was to explore and understand the functioning of MELs; and the second was to explore the novel use of the DiCoT method for multisite comparison studies. Specifically, for a HCI audience, this gives an assessment of a relatively new function for hospitals with potential for socio-technical design input; and it suggests a novel use of a method that can be used for direct comparisons between different socio-technical contexts more broadly.

5.1 Validation

The results reported here have been shared with four practitioners with differing backgrounds. Two of the validators have set up MELs in their career and are involved in enhancing work processes. The other two are currently undergoing the process of setting up or reorganizing an existing MEL and are relatively new to the concept of managed MELs. In order to get feedback in a structured way, all validators were asked to answer a short questionnaire with the following questions:

- a) Did you find the report interesting?
- b) Did you miss certain topics or facts you think should be included? If yes, which?
- c) Did you find the report or parts of it useful in any way?
- d) Did you learn anything new from reading this report?
- e) Is there anything else you would like to comment on?

One practitioner from MEL1, which was the main data point, was available for a one-on-one interview. This facility has been busy making changes to the structure and organization of the MEL in the time between our observations and the validation of the findings. Points of agreement concern the distinct segregation of the four areas (clean, dirty, office and repair), the handling of out-of-hours (improved monitoring), unique identification of equipment (introducing short codes) and fixed collection times (two collection rounds a day). The latter idea was examined even further by extending it to the delivery of equipment. By having fixed delivery times (about every three hours), the work of equipment coordinators could be structured more efficiently. A novel idea to MEL1 is the T-card system and the features it brings to the library. For this and many other reasons, the findings and recommendations proved to be very insightful for MEL1 and will contribute to their developing practice.

Overall, the validators found the analysis interesting and informative. Practitioners who were less familiar with MELs found the report most useful, as there was lots of information they could extract from it. The best practice examples and issues of concern proved to be useful, especially for managers who are in the process of setting up or improving a MEL. They found the results useful for guidance and inspiration as well as for confirming their own ideas. More experienced practitioners agreed with most of the findings, although some of them were classified as impractical due to their high cost (e.g. RFID tagging, relocation of library, nurses attending staff meetings).

5.2 Design opportunities and requirements

At the outset of this study it was not clear what technological support existed, what design opportunities might be appropriate for this context, and what the socio-technical challenges were. Reflecting on the insights from our analysis we highlight five areas that warrant further investigation. Here we intentionally generate HCI design and research questions to open up this area to further work, to improve this service function:

5.2.1 Improved identification and tracking of equipment

In section 4.1.2.2. we highlighted that device tracking is an issue of concern in current MEL practices. Equipment gets lost or disappears for certain time periods, because devices are needed for transferring patients and therefore leave the area of observation. When equipment is removed from the library during out-of-hours without complete documentation, it is difficult to track these items or control stock properly. Some MELs use CCTV to monitor which equipment is taken by whom. However, this requires effort to check T-card status', information is filled into forms and the database, to perform stock inventory checks, and to follow-up with what was observed on CCTV. Considering what technology offers these days it seems to be a possibility to explore device tracking further in order to allow for an improved service. Barcodes and QRcodes are already used in book libraries for self-checkout for example, which is a simple process. However, scanning this information only documents removal of equipment, but does not capture minimum information about destination and duration. To support the checkout process, electromagnetic technology can be used to set off an alarm that reminds staff to checkout their items. Also, using a system like this requires a check-in process in order to allow identifying current location of equipment. RFID tags or GPS can offer real-time tracking of devices. However, after participating in a trial run, MEL3 suggests that execution, overall cost and maintenance of such a system needs to be improved.

Table 1. Claims analysis of best practice examples

Feature	Pros (+) or Cons (-)
Unique identification of equipment	(+) Minimizes miscommunication and misunderstandings between wards and departments, the MEL and porter service (+) No need for untrained or inexperienced staff to remember complicated names, models and makes of equipment introduction of such a new system can lead to confusion
Out-of-hours handling	(+) Equipment is collected, cleaned, maintained and available also during weekends; reduces risk of equipment shortage (+) Incomplete paperwork and the tracking down of therefore lost equipment is kept to a minimum (-) Weekend shifts increase staffing costs (-) Operating an extra out-of-hours store means extra effort
Equipment usage reports	(+) Easy monitoring of MEL (+) Allows to identify trends and issues
Monthly staff meetings	(+) Opens up a communication channel for all parties interacting with or through the MEL (-) Takes up extra staff time
Central location of equipment library	(+) Reduces the risk of equipment overuse or damage (+) Allows easier out-of-hours management (-) Difficult to realize because space and premises are often unavailable
Reduced paperwork	(+) Reduces redundancy of information and transfer errors (-) Removes paper backup
Color-coded T-card system	(+) Enables overview at one glance (+) Easy system for keeping records (-) It can be easily forgotten to place the T-card on the panel
Standardization and training	(+) Standardization reduces equipment cost (+) Training becomes easier and more efficient (+) Risk ratings increase patient safety (-) Disposal of outdated equipment requires effort (-) Procurement process needs to be initiated

Table 2. Claims analysis of issues of concern

Feature	Pros (+) or Cons (-)
Labeling of storage	(+) Labels on shelves make it easier to find and restock equipment, especially for inexperienced staff
Out-of-hours handling	(+) Equipment is collected, cleaned, maintained and available also during weekends; reduces risk of equipment shortage (+) Incomplete paperwork and the tracking down of therefore lost equipment is kept to a minimum (-) Weekend shifts increase staffing costs (-) Operating an extra out-of-hours store means extra effort
Device tracking	(+) Avoids losing equipment, which results in cost savings and less effort tracing equipment (+) Software updates could be distributed more easily (+) Tags can send alerts (when service is due or equipment is faulty) (-) Very expensive (-) Pilot projects have not convince staff of the benefits RFID brings in comparison to the T-card system
Socially clean equipment	(+) MEL could work more efficiently if cleaning is done properly by the wards and departments (-) The risk of cross infection could be minimized (-) Nursing staff spend more time on cleaning
Equipment collection	(+) Scheduled collection times are more efficient for the MEL (-) Wards will want equipment delivered and collected quickly (-) Requests for pressure relieving equipment collection must be treated independently
Health and safety regulations	(+) Risk of infection can be minimized (-) Staff need to be instructed, reminded and controlled regularly (-) Some regulations interfere with practicality
Lighting conditions	(+) Better lighting conditions ease work and enable precise work (-) New installments and adjustments cost money, time and effort
Best practice sharing	(+) Can inform current practices and result in improved systems (+) Can inspire new ideas and innovations (-) Bears the risk of spreading ideas that can have a negative impact on current practices
Pressure relieving equipment	(+) Good management decisions results in cost savings and a better service (-) Bad management decisions increases cost and hinders the service (-) Finding the best solution takes time

5.2.2 Better administrative systems

Several points have been made about keeping records, including paperwork, database systems and T-card panels. MEL2 keeps administration to a minimum with a simple paper request form that can be filled in quickly and is almost immediately entered into the database, so that the paper forms can be archived and put out of the way. However, MEL1's procedures include a lot of redundancy, i.e. transferring information from notes to paper forms to database, which seems more error prone and time consuming. As the largest library we visited for this study, it also does not make use of the T-card system, which would enable a better overview of stock and current equipment locations. This is an area that offers various opportunities for HCI to arrive at innovations for MELs. A few of the questions to answer are: Can we translate the T-card system into a digital version that is linked to an improved sensor-based device tracking system? Can we widen the approach and let devices communicate their current location and state to the base? How do we back up appropriately? How do we maximize equipment usage reports to save the hospital money in loan fees and procurement costs? One of the biggest challenges is to integrate all the information that is necessary for a loan request. Currently, the patient's name, the ward or department, the duration, the purpose and the person who requests the equipment are some of the data captured for each request. This information may be missing in busy hospital environments where urgent requests play a major role. Here filling in paper forms, placing a T-card into its slot and scanning the device may be neglected by staff in certain situations. RFID tags for example can be programmed to communicate with other tags, which would allow for linking a device to a ward or department, the taker, as well as a patient, if both use the same technology. Information about duration and purpose could be retrieved from the patient's file; however, privacy and security are a major issue.

5.2.3 Solutions for out-of-hours working

Section 5.2.1 addresses issues that strongly relate to MEL out-of-hours, where librarians are not present to deal with paperwork, information capturing and day-to-day library tasks like cleaning devices, charging batteries and keeping the library tidy. Solving the issue of leaving a messy and under stocked library behind is a tricky challenge to tackle. One example where out-of-hours handling works quite well is outlined in section 4.5.1.1, where MEL1 maintains a separate room with a smaller selection of devices that are most likely to be needed during these hours. However, physical constraints rarely allow for an extra room. Hence in all other places, the full equipment library is accessible for hospital staff via ID card. The ID card contributes by gathering information about who has taken equipment and at what time. Full access results in an empty library on Mondays, when equipment needs to be collected, cleaned and maintained in the morning in addition to comparing loan requests forms to stock. A system that highlights discrepancies (checked-out versus checked-in versus registered equipment for example) would support this process.

5.2.4 Better knowledge sharing and support between practitioners

The Evolutionary Model has shown that official standards and guidelines for equipment libraries are relatively young and best practice sharing amongst practitioners seems limited to a platform that the EBME has set up. In our study, we approached people who are new to managing equipment libraries as well as practitioners who have been involved from the beginning and contributed to developing the various documents listed in section

4.1. We also know from interviews that practitioners find ways to share their work through open days and word-of-mouth. These formats are rather informal and only benefit a small percentage of all equipment libraries. Our small-scale study uncovered a number of good practices and ideas already. We are certain that there is much more to discover which would benefit large as well as small equipment libraries. In the UK the National Association of Medical Device Educators and Trainers has recently been established, which has an interest in MELs and their operation. We know there are developed online community support tools, but it is not yet clear what would benefit this and similar groups in terms of reporting and sharing best practices specifically.

5.2.5 Usage of physical space and dedicated areas

A big issue of concern was the limited space most MELs are constrained with, especially when dirty, contaminated equipment and clean, fit-for-service equipment are stored and handled directly next to each other. MEL1 has made arrangements to address this issue and segregate clean, dirty office and repair areas more distinctively, in order to avoid contradicting one major purpose of the library, which is providing clean, de-contaminated equipment for safe use. Other libraries do not have this much physical space and therefore need to explore other options. Do we have opportunities to improve shelving to protect clean equipment from potential exposure? For example by installing transparent doors or spray disinfectant whenever a hand or device reaches over the edge? Can we separate areas more clearly and install a warning system in case equipment enters a zone it should not be in? For example, if the state of a device was known via RFID, it could alert staff when placed in the wrong area. In MEL1 a message about some infusion pumps was left on a sticky note on a side table for the next shift. If the sticky note had fallen off or the message had been misunderstood, the actual state of the pumps would not have been known.

5.2.6 Conclusion

This analysis has revealed the basic mechanics of MELs, which is one of the purported uses of DiCoT [3]. This is useful for such a new hospital function that has not had this type of analysis before. Furthermore, it has raised issues and best practices that interestingly will be more or less applicable depending on the context of specific MELs. For example, some healthcare contexts may be closed at weekends and so not suffer the issue of out-of-hours operation. In contrast a large busy hospital might have the resource to provide cover in these periods, which would be much quieter in less busy hospitals. The five research areas that we have highlighted above have sought to map out fruitful areas for HCI experts to contribute to.

5.3 Using DiCoT for multisite comparisons

This multisite study of three separate MELs has revealed that some practices are better than others, and that best practices are not being effectively shared. This should not be a surprise, and to some extent confirms our suspicions that evolved practices in healthcare vary. Some of these practices will be more efficient, effective and safer than others. What seems important is to try to better articulate what these practices are so they can be shared and explicitly considered in the development of healthcare services.

The contribution of DiCoT is that it supports the systematic analysis of a socio-technical system through developing five models. This study has shown that issues and best practices can be identified in each of the five models using observational data from various sites and expert interviews. Without a multisite study or including at least some data from other contexts it is difficult to

identify best practices. Some form of comparison seems almost essential in these instances.

Using DiCoT for multisite comparisons has been a novel use of the method. Future work will include exploring whether this use needs specific advice or adaptations for this type of study. For example, in this study we had one primary site, MEL1, and used supporting sites and interview data for contrast and comparison. This might be advisable for future studies too.

Multisite comparisons also seem to be a fruitful area for healthcare services. It is not at all clear that the evolved practices between different sites behave similarly and so sharing best practice could improve the performance of services in a practical and targeted way, i.e. if another similar service manages their work in that way and it has led to benefits then perhaps the receiving service needs to seriously consider it too. Future studies plan to explore this work. This endeavor supports the better evolution of healthcare systems based on what is going on already. A further point of contribution in these studies is to recognize general issues that multiple sites have in common that could lead to design opportunity and other socio-technical interventions. For example, none of the sites we observed had developed systems for tracking device even though this was recognized as a common issue. Technological advances in this area could lead to improvements across many MELs.

6. CONCLUSION

In this paper, we outlined the results of our multisite DiCoT analysis of medical equipment libraries and their practices. DiCoT with its five models proved to be a useful framework to structure the rich amounts of data we gathered from multiple data points and allowed us to draw out issues and best practices for each of the models. There is good work that is going on in pockets of the healthcare sector but it seems that these best practices are not being shared effectively – this paper is a first step to start sharing best practices and issues for MEL at an operational level. These issues and best practices also highlight areas for design opportunity. We have drawn out five areas that warrant further investigation and attention to improve the service a MEL offers to healthcare. To be addressed effectively these need cooperation between managers, MEL workers, HCI researchers and designers.

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