IoT Enabled Biomedical Waste Management System

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Abstract

Sustainable management of Biomedical waste has become an increasing concern to governments and healthcare facilities around the world. As per World Health Organization (WHO) report about 75–90% of Biomedical waste are nonhazardous, and the remaining 10–25% are hazardous. The amount of Biomedical waste produced and its characteristics depend on many factors such as type of Health Care Facilities and the specific area within the health care facilities that generates the waste, and patient flow. This research work involves conduction of an exploratory survey to identify the problems and pain points in biomedical waste management system and digitization of the biomedical waste management system using an IoT architecture. A prototype of digitized bag was developed that sends the unique ID and weight of each bag to the application database. This data can be used for multiple applications including route optimization and pilferage reduction.

Keywords: *Biomedical waste management, Internet of Things, Bio-medical Waste Management*

1.0 Introduction

Poor management of Biomedical Waste (BMW) exposes health-care workers, waste handlers and the public to infections, toxic effects and injuries. Sound management of BMW is an important part of environmental protection. A number of countries across the globe have national policies, guidelines and action plans, as well as best practices on Biomedical Waste Management (BMWM). However, the process of BMWM may vary from country to country, as some are at a more advanced level of development than others. There is a need to take account of the status of BMWM in countries in order that gaps may be identified and future support programs may be informed.

The number of Health Care Facilities (HCFs) in India is on the rise, making healthcare accessible to more people and also generating more waste in their treatment. As per Central Pollution Control Board (CPCB) Annual Report Information 2017, there are 2,38,254 HCFs in India, out of which 87,282 are bedded facilities with 20,94,858 beds. BMW is being generated at each of these facilities, collecting, moving, and disposing of biomedical waste from each of these locations is an enormous challenge. Ministry of Environment and Forests, Government of India issued guidelines governing BMW in July 1998. These

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guidelines deal with issues such as definition, categories of segregation of waste, protection and handling the waste, treatment of waste [1]. An amendment to Biomedical Waste Management (BMWM) rules was passed in 2016. The new rules simplified the classification of BMW and authorization, thus improved handling of BMW [2].

Mathur, et al. [3] discussed the need for a BMWM system, the sources of biomedical waste, its categorization and disposal. Ira F Salkin et al. [4] listed the health impact due to spread of microbial hazards and BMW. Greesham Tony et al. [5] carried out a system analysis of BMW process in clinics in Udupi Taluk in 2018. The study revealed that majority of the clinics had inadequate BMWM equipment, training and failed to meet the BMWM guidelines.

Seetharam [6] discussed the case of study of Hepatitis-B outbreak in Gujarat in 2009. Over 240 people were infected and 70 succumbed to the disease during the outbreak. The cause of outbreak was identified as use of unsterilized syringes and needles, which were pilfered from used medical equipment. A study was carried out by INCLEN Program Evaluation Network (IPEN) Study Group [7] to evaluate the state of BMWM system all over the country. Data was collected from across 20 states of India and was found that 82% of primary health centers, and more than 50% of secondary and tertiary care health facilities had inadequate BMWM system. Dr. Sushma Rudraswami et al. [8] looked into the global statistics of BMW generation. Kumar et al. [9] examined the transportation of BMW within a healthcare institution. It was found that waste bags from various locations were not being cleared on time, uncovered trolleys were in use and sharp containers were improperly closed, and only 0.66-1.12% of staff used protective equipment while handling waste.

K Usha Krishnan et al. [10] tested the efficacy of the training for BMWM. The results showed that participants felt an improvement in practices post training. Matthew et al. [11] studied the BMWM practices among healthcare workers and found that they are ignorant of sound BMWM practices and yet injury reporting was low for all groups of healthcare personnel.

Shyam et al. [12] and Soni et al. [13] implemented IoT Technology in waste management by integrating sensors which collects' information from the garbage bin for live monitoring of the state of the waste. Hong et al. [14] developed and implemented an IoT based garbage system for food waste management and the pilot project showed reduction in food waste Raundale et al. [15] discussed various technologies available to automate management and handling of BMW. IoT based sensors are proposed to collect and store data on BMW which can be used to improve the process.

There is a need for proper collection and disposal system for BMW waste. Guidelines that regulate management of biomedical waste were notified by government and regulatory bodies. But gaps exist between statutory requirements and the BMWM systems in practice. The objective of this research work is to conduct an exploratory survey to identify the problems and pain points in BMWM system and digitization of the bio medical waste management system using an Internet of Things (IoT) architecture.

2.0 Biomedical Waste Management - Process

The BMWM process, illustrated in Fig. 1, begins with waste being generated as a by-product of healthcare functions like treatment, diagnosis etc. At the place of generation, the waste is identified, segregated and disposed of into the right colored bin according to the color code shown in Fig. 2.

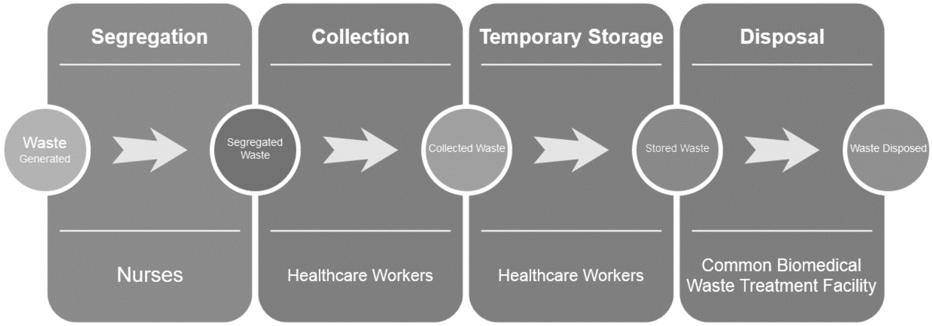

Fig. 1. Biomedical Waste Management Process

Waste from all the bins are collected and moved to a temporary storage, usually outside the hospital premises or in the basement. The waste is stored in temporary storage until time for disposal. Regulatory requirements state that waste shall not be stored for more than 48 hours [3].

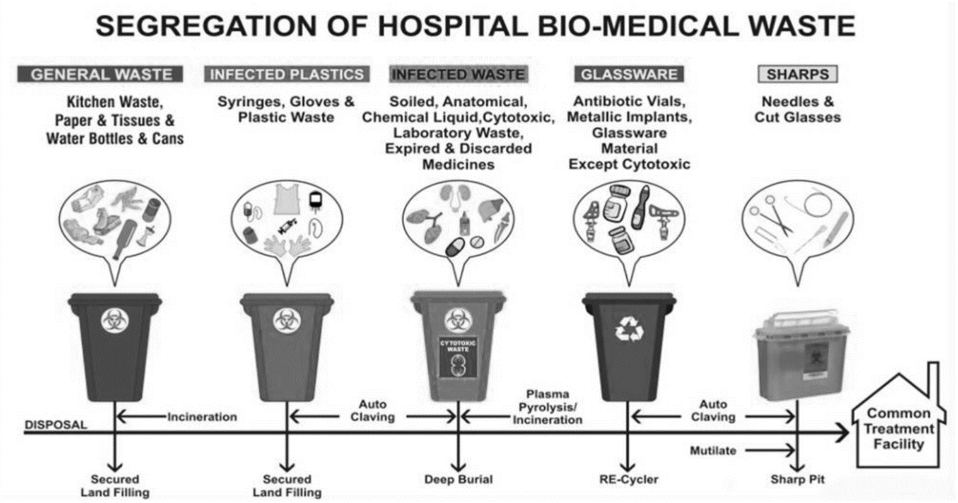

Fig. 2. Categorization of biomedical waste and its disposal methods

The disposal process may be done either at on-site or off-site facilities owned by hospitals, if Common Bio-medical Waste Treatment Facilities (CBWTFs) are not available in a radius of 75km. A bar coding system which is aimed at ensuring waste is accounted for, from generation to disposal, so that waste is not disposed of illegally or using wrong methods has been introduced by law. It also brings accountability for the waste as any bag of waste can be traced back to the hospital. Any discrepancies in the bag of waste have to be reported to the respective state pollution control board.

3.0 Exploratory Study - Summary

Initially a pilot study was carried out, that gave insights into the current BMWM system and inputs for designing and conduction of study. Final survey was conducted for a sample size of 110 HCFs and the results were analyzed for relative importance of the factors causing pain points in the BMWM process. The BMWM practices were reviewed to identify the gaps in the system, opportunity for digitization using IoT architecture and exploring possibility of integrating the current KSPCB bar/QR coding guidelines.

The HCFs were asked to rate the awareness of risks among the person(s) who directly handle BMW. The average rating was 70.68 with a standard deviation of 21.48. It was observed that large HCFs have a higher average rating than small HCFs.

The regulatory requirements state that BMW must be stored in the HCFs for a maximum of only 2 days. However it was observed that most of small HCFs are storing BMW for up to 3 days with only 1.4% with everyday collection. The HCFs do face some problems with the segregation of waste. Training of health care workers on BMWM is mandatory by law. The larger HCFs have planned their internal waste collection periodically instead of collecting only when the bins are full. The temporary storage of BMW is the final process carried out within the HCF. This stage involves keeping the BMW in a specially designated area, usually outside the premises of the HCF.

Stratifying the results into small HCFs and large HCFs, it is observed that small HCFs have more of a problem with lack of space and long storage times (due to infrequent collection by CBWTFs). Mann Whitney U test was performed on the data to test if there is actually a difference between small and large HCFs. The results at a confidence level of 90%, show that there is a difference in the median response for small HCFs being higher than the median response for large HCFs. Therefore they face more of a problem with CBWTFs collection frequency.

4.0 Development of IoT Enabled BMWM System

Findings from the exploratory study reveal that the improved collection, transport and disposal are the fundamental requirement for resolving BMWM problems. The overall IoT architecture developed is shown in Fig. 3.

4.1 Design Input Examination:

The exploratory study provided some useful information about the system such as how often the CBWTFs visits the hospital, number of segregation points in the hospital and common difficulties and problems faced by the hospital. It was found that very few hospitals had systems in place that adhered to the guidelines set by the government. Two Hospitals were identified and the existing process of BMW process was studied in detail to understand the process and requirements for IoT based BMWM system.

4.2 Functional and hardware design

IoT based BMWM system functional design was carried out. The components, modules and subsystems of the IoT architecture were listed.

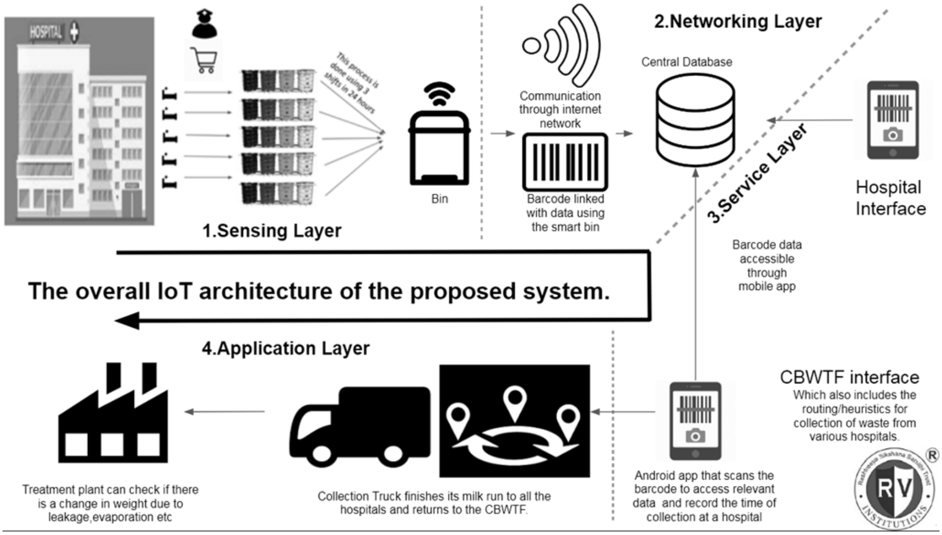

Fig. 3. Four layered IoT Architecture

4.3 Software design

The software was designed such that it has separate logins for HCFs and CBWTFs. Once logged in the user can scan the barcode using the camera to save the weight of that bag and link it to the bag ID. The data is transferred over the Wi-Fi network and stored at the central database. Separate mobile app interfaces was developed for HCFs and CBWTFs to ensure smooth operation of the system and shown in Fig. 4 and 5.

App flow design for CBWTF interface: The app that is developed is called BioCollect and works with two different interfaces, one for the hospital employees and another for the CBWTF employees. The app interface is designed in such a manner that it is easy for any personnel to understand and navigate through the app. The user has the option to register himself / herself if it is a new user or just enter the login credentials (email ID and password) and click on login to enter the app. Once the user has logged in, the dashboard is displayed. The dashboard contains four options to choose from for the user. The user can click the first option to view the BMW records already available and receive a report of the records which can be downloaded or printed date wise.

The second option on the dashboard is the option to view the CBWTF upcoming scheduled visits, last visit details etc. This will aid the CBWTF to keep track of all their waste pickups and drops. The third option on the dashboard is the QR/barcode scanner. This will open the camera scanner and wait for the user to scan the QR/barcode. Once it is scanned the first time before pickup, it will save the weight of the bag. Afterwards, when the bag is scanned just before it is sent for disposal it will check the value of the weight stored and display the pilferage percentage. The last option is the routing heuristics, which help the CBWTF driver take the optimal route while going from hospital to hospital to pick up the biomedical waste. The above app interface is illustrated in Fig. 4 and 5.

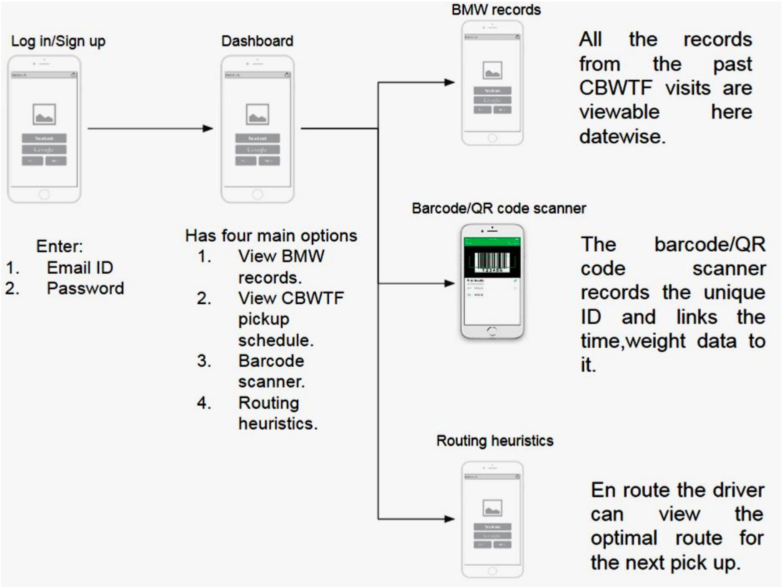

Fig. 4. Mobile app flow for CBWTF interface

App flow design for Hospital interface: The app flow for the hospital interface is very similar to the CBWTF interface in the sense that the login credentials and the login page as well as the register new user page remain the same. Once the hospital user has logged in, the user can view the three main options available. The first option is the option to view all the BMW that has been moved from the hospital to the CBWTF in the past and the option to view it in a report format date wise. The second option is to open the QR/barcode scanner and record the weight of the bags in case the initial weight check is done the hospital. This functionality is added to the hospital interface to make sure that either the hospital or the CBWTF can do the scanning and recording of weight as per whatever the understanding is between the two parties. The third and final option available to the hospital personnel on the dashboard is the option to view the CBWTF scheduled upcoming visits in a date wise format so that appropriate actions are taken from the hospitals side to prepare for the upcoming CBWTF visits.

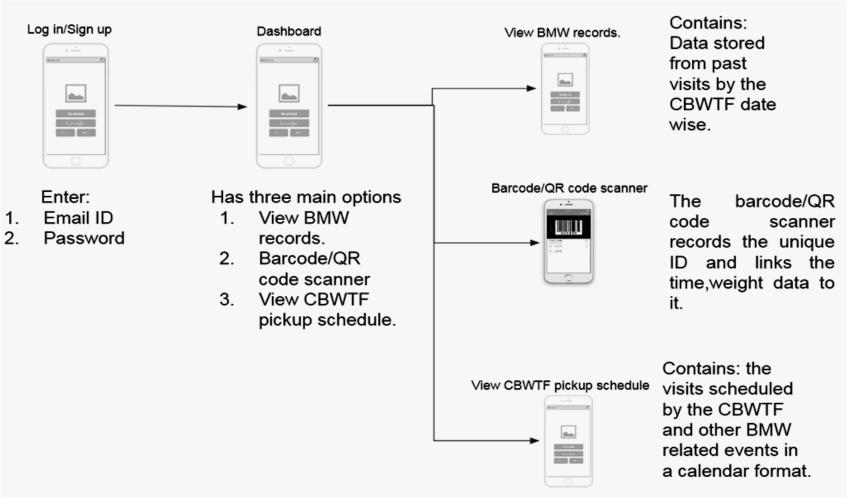

Fig. 5. Mobile app flow for hospital interface

4.4 Prototype Development

The prototype (shown in Fig. 6) houses the 4 load cells, HX711 amplifier, ESP32 Wi-Fi module, load cell combinator, Arduino UNO and the wiring. The ARDUINO board was coded on the IDE platform to enable the data sensing, data relay and data calibration.

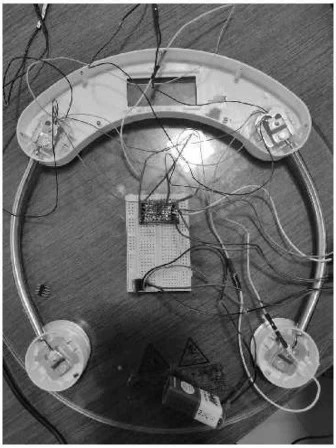

Fig. 6. Prototype circuitry

A specific casing design was developed to house the prototype and make the whole circuit compact, allowing it to be highly portable. Bio Collect app that facilitates the digitization of the weight collection routine, also complying with the required biomedical waste management guidelines was developed. The guidelines by the government require HCFs to have a digital record of the weight generated at the facility and the disposal agency to adopt a QR code or barcode scanner app to log the weight collected and later be able to check any possible pilferage. The integration of hardware and software leads to the total digitization of the BMWM system. The hardware components function to sense the weight data, calibrate and relay to the app the sensed data over a Wi-Fi network. The app allows for the scanning and logging of the relayed data. A digital dashboard for the specific stakeholders is provided in the app to display a recent history of waste collections for a better understanding to further improve biomedical waste management.

5.0 Results

5.1 Conformity to government guidelines.

The digitization of the bio-medical waste management system has been beneficial for both HCFs and CBWTFs to adhere to the government guidelines.

1. The barcoding system has been accommodated through the use of a bar/QR code scanner in the app which identifies the unique ID of the bag, reads all the static data stored and links the weight of the bag to the ID.
2. The policy which states that if bags undergo more than a 10% change in weight due to pilferage the amount of pilferage and time of occurrence has to be reported has been incorporated by the proposed system through time stamp recording and alert messages after the final scanning in the project above if the pilferage exceeds 10%.
3. It is mandated that all the data regarding bio-medical waste collected by the CBWTF be stored by the CBWTF for a stipulated period of time on a web based platform which is being done as the data regarding the waste collected by the CBWTF is stored on the apps server until it is requested to be cleared by the CBWTF.

5.2 Ease of use

The data generated by weight modules and stored on the web platform has facilitates the following:

1. There is a very high amount of data visibility as the exploratory study revealed what kind of data is relevant and important for both the HCF and CBWTF.
2. The data transparency factor is also vastly improved due to the fact that it can be easily accessed by any personnel who has the app and has registered on the app with his email ID and password.
3. Automation of the recording process has reduced the number of personnel required for this process to one. A single person can place the waste bag on the weighing module and then scan using the mobile app to record the waste in that bag onto the online platform.

6.0 Conclusions

The main pain points in BMWM activities segregation, collection and storage of wastes and noncompliance of government guidelines were addressed by the IoT enabled BMWM system. Implementing IoT based BMWM system has led in increasing operational efficiency and decreasing BMWM costs in HCFs. Web based platform facilitate tracking the bio-medical waste by multiple parties such as the government bodies, the hospital and the CBWTF.

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Appendix-Exploratory Study

The exploratory study of BMWM system was conducted and the Fig. 4 illustrates the steps in the study.

Survey objectives

- To identify the pain points in existing Biomedical waste management system.
- Digitization of the bio medical waste management system using an IoT architecture that integrates the current KSPCB bar/QR coding guidelines.

Design and Development of Survey Queationnaire

- Questionnaire - 6 sections :
  - General information
  - Information on risk awareness and disposal methods
  - Factors affecting segregation, collection, movement and storage
  - Market perception
- Likert 5 point scale used to measure factors.

Content Validity and Pilot Study

- Experts examining the survey items for ambiguity and redundancy
- Survey answered by hospital administrators in charge of biomedical waste management

Administering Questionnaire

- Questionnaire administered online on smartphones by hospital administrators
- Total Hospitals Approached - 170
  - Response received - 110
  - Rejected questionnaires - 60

Data Analysis

- Relative importance of each factor in the three categories
- Data stratified into Small HCFs and large HCFs. Differences in median of factors for the two subsets tested using Mann - Whitney U test.

Digitization model

- Selection of 2 hospitals
- Brainstorming Session
- Decision to develop IoT model for BMWM

IoT product development

- load cells that read the weight signal,
- an amplifier to convert the signals to a digital format,
- a WiFi sensor
- module to transmit the data via a WiFi network to a central database
- CAD model
- Prototype development
- Android development

Fig. A1. Steps in conduction of the study

Development of Survey and Conduction of study

The survey questionnaire was structured on a framework for rapid assessment of BMWMs, developed by World Health Organization (WHO). The survey questionnaire contained items that categorized the HCFs, as private or public and also based on the number of beds in the HCFs. Questions with Likert scale were used to test participants' agreement to certain factors causing problems in various steps of BMWM process in the HCFs. Further, the HCFs were asked about their perception of IoT enabled BMWM system, their interest in implementing such systems. These questions were designed to evaluate the HCFs readiness for digitization or automation of BMWM. A convenience sampling approach was used for HCFs in geographical regios covering Bangalore North, Bangalore South and Bangalore East. Anonymity was ensured in the surveys. 110 responses were collected. The respondents were approached personally and the responses were recorded online on smart-phones.

Study Findings

The complete set of responses was first analyzed and descriptive statistics for various types of questions were computed. The responses were stratified based on capacity of HCFs. Complete statistical analysis was then carried out on the two subsets. For the Likert scale type data Kruskal Wallis and Mann Whitney U test (non-parametric tests) was carried out on samples from both subsets to test if the results were statistically different from each other. Among the respondent HCFs, 101 were from private HCFs and 9 were from the public sector. For analysis, the HCFs were subdivided into small HCFs (Clinics and hospitals under 30 beds – 68% of respondents) and Large HCFs (Hospitals with more than 30 beds – 32% of respondents).

The HCFs were asked to rate the awareness of risks among the person(s) who directly handle BMW. The average rating was 70.68 with a standard deviation of 21.48. Table 1 shows the summary of the responses recorded. These figures are however the perceptions administrators with respect to the awareness of their employees. These numbers need to be higher as the risk posed by BMW is really high, including contracting fatal diseases and infections. One can observe that large HCFs have a higher average rating than small HCFs.

Waste Collection Frequency

The regulatory requirements state that BMW must be stored in the HCFs for a maximum of only 2 days. However it was observed that most of small HCFs are storing BMW for up to 3 days as the waste is being collected by the CBWTFs once in three days, as shown in Table 1. Most of the Small HCFs have collection frequency of every three days, with only 1.4% with everyday collection. However in large HCFs collection was every 2 days for over 75% of them. The waste collection frequency can be increased using IoT technology to track fill level of bins and optimizing collection routing.

Segregation of BMW

The respondents were asked to record on a scale of 1 to 100, to what extent they agree with the statement “There is trouble in identifying the right bin to dispose the waste in” and the results are shown in Table 1. One can observe from the frequency distribution that some kind of clustering of responses are on the scale. It can be inferred that HCFs do face some problems with the segregation of waste. The perception is that human error and lack of experience are the major causes of this problem, and cost is not a significant factor. This should mean that segregation issues should naturally reduce as employees get experienced on dealing with the various types of waste. Training is mandatory by law. Visual aids at the point of segregation like charts showing the right segregation can be used to aid decision making for segregation.

Table A1. Summary of the findings

	All HCFs	Small HCFs	Large HCFs
Awareness rating			
No. of participants	108	74	34
Average	70.68	68.16	76.24
Mean Absolute Deviation	17.16	18.80	12.99
Standard Deviation	21.48	21.10	16.34
Waste collection frequency in %			
Everyday	26.5	1.4	51.6
Every 2 days	26.0	26.2	25.8
Every 3 days	39.2	59	19.4
Weekly	8.3	13.4	3.2
Segregation of BMW (0 - Disagree, 100 - Agree)			
Average	38.44	54.2	22.68
Mean Absolute Deviation	23.47	25.62	19.63
Standard Deviation	25.67	22.87	20.69
Collection of waste, opinion (0 - Disagree, 100 - Agree)			
Average	31.18	52.12	18.62
Mean Absolute Deviation	19.07	17.12	22.02
Standard Deviation	23.32	18.02	23.56

Collection and Storage of Waste

The collection of waste in color coded plastic bags from various bins across the facility and then moving to a central location for temporary storage. It is observed that majority of the respondents are in 0-30 % band of the scale. Small HCFs usually have little to no trouble with collection of waste as the bins are less in number. So it is easy to track waste and collect regularly from all locations. However, it becomes significantly harder as the size of HCF increases. Tracking of waste from hundreds of bins in large facilities becomes an operational challenge. And number of healthcare workers increase leading to increased cost of operations.

The primary factor is considered to be human error, an oversight in collection from bins which is the reason for irregular collection. Lack of information on the amount of waste collected in bins and may seem like a major issue in collecting of waste in large HCFs. But the survey results say otherwise as larger HCFs have already planned their internal waste collection periodically instead of collecting only when the bins are full. Therefore, information is not considered necessary for collection of waste from bins.

The temporary storage of BMW is the final process carried out within the HCF. This stage involves keeping the BMW in a specially designated area, usually outside the premises of the HCF. Yet, simple storage of waste can have a lot of problems. Some factors and their perception are illustrated in Fig. A2. Stratifying the results into small HCFs and large HCFs, it is observed that small HCFs have more of a problem with lack of space and long storage times (due to infrequent collection by CBWTFs). To test if there is actually a difference between small and large HCFs, Mann Whitney U test was carried out on the data and are shown in Fig. A3. Based on the results of the Mann Whitney U test, it can be said that at a confidence level of 90%, that there is a difference in the median response for small HCFs being higher than the median response for large HCFs. Therefore they face more of a problem with CBWTFs collecting waste from small HCFs every three days and once a day for large HCFs, as mentioned before.

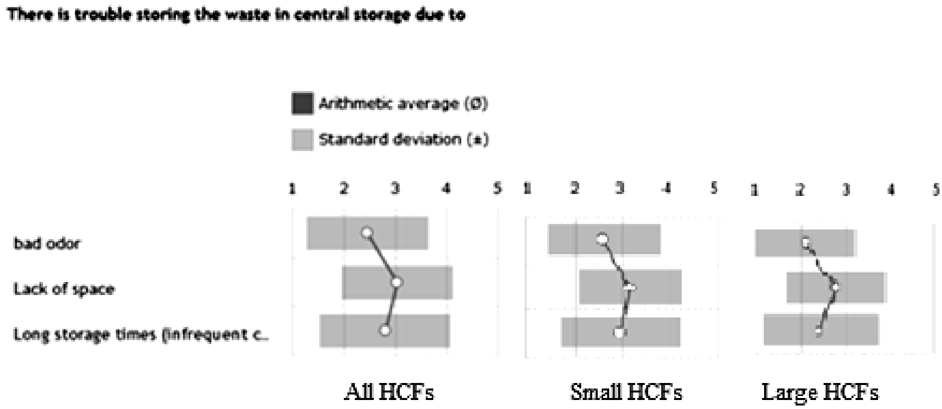

Fig. A2. Issues in storage of waste

Results for: Hospital Higher.MTW

Mann-Whitney Test and CI: Lack of space_Higher, Lack of space_Lower

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                      N  Median
Lack of space_Higher  34  2.5000
Lack of space_Lower   73  3.0000

Point estimate for η1 - η2 is -0.0000
95.0 Percent CI for η1 - η2 is (-0.9996,0.0001)
W = 1610.5
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.1322
The test is significant at 0.1143 (adjusted for ties)
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Mann-Whitney Test and CI: Long storage tim, Long storage tim

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                                    N  Median
Long storage times (infrequent    34   2.000
Long storage times (infrequen_L   73   3.000

Point estimate for η1 - η2 is 0.000
95.0 Percent CI for η1 - η2 is (-1.000,-0.000)
W = 1580.0
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0874
The test is significant at 0.0783 (adjusted for ties)
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Fig. A3. Mann Whitney tests