An Investigation into Solid Waste Accounting Methods for the new SUB

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1.0 Abstract

As part of UBC's strives towards becoming a waste-free campus under the Climate Action Plan, the Alma Mater Society (AMS) is looking for best waste accounting practices to be implemented in the new SUB. This report looks at the different methods of waste accounting/auditing done at other campuses, suggests methods for conducting waste audits, and evaluates these methods using the triple bottom line assessment. The two methods suggested are: a manual method and a mechanized method. The triple bottom line assessment shows that the manual method is more cost-effective, and has a great potential to increase student involvement in UBC's sustainability efforts and is hence recommended to be most suitable for the current context. However the mechanized method is suggested as a long-term solution as it presents promising environmental benefits of diverting waste from the landfill, which helps to fulfill UBC's ultimate goal of a zero-waste campus.

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Glossary

Mechanized: To introduce machines or automatic devices into (a process, activity, or place)

Sorting: The process of arranging waste in different sets according to types

Broadband radiation: Radiation with a large range of frequency generated from X-ray source

Unsorted waste: Waste collected in the new SUB building

Spatial resolution: The measure of how closely lines can be resolved in an image

Custodial staff: UBC staff responsible for the collection and removal of waste from buildings.

2.0 Abbreviations

SUB: Student Union Building

AMS: Alma Mater Society

UBC: University of British Columbia

PVC: Polyvinyl chloride

XRT: X-ray Transmission

XRF: X-ray Fluorescence

EM: Electro-Magnetic

IR: Infrared

LPF: Low-Pass Filter

MCU: Microcontroller

ADC: Analog to Digital Converter

e-waste: Electronic Waste

3.0 Introduction

University of British Columbia (UBC) is working towards being a zero waste campus. As one of the major buildings under construction and an essential gathering place for student interaction at UBC, the new SUB is also aiming for the same goal of being a sustainable building.

The first step towards becoming a zero waste building is to effectively account for the solid waste generated in the new SUB. Waste needs to be regularly accounted for in order to be able to act upon based on the accounting results. The majority of waste accounting methods used today are a form of manual waste auditing. However, many of the existing manual auditing methods are found to be old-fashioned, less efficient and labor intensive.

This report aims to investigate the different solid waste accounting methods currently used in other universities. Subsequently the report attempts to offer some recommendations for waste auditing in the SUB, based on a triple bottom line assessment—evaluating the best solution from the social, economic and environmental perspectives.

There are two methods being investigated and compared: the manual and the mechanized method. Manual methods include the collection of waste data through auditing-by-hand and mechanized methods include automated sorting machines for waste accounting. The primary and secondary sources used for this investigation comprises auditing reports of major universities, AMS auditing reports, as well as interviews with the SUB stakeholder and a waste sorting industrial specialist.

Based on the triple bottom assessment, recommendations are suggested, from both short-term and long-term perspectives. The short-term recommendations focus on achieving practical and realistic results while minimizing increases in budget and resources whereas the long-term recommendations focus on achieving the ultimate vision, providing a more permanent and efficient technological solution for future waste auditing.

4.0 Waste Auditing Method

Section 5 outlines the two main methods of waste auditing being considered, mainly the Manual Method in 5.1 and the Mechanized Method in 5.2.

Section 5.1 is further divided into two: 5.1.1 address the question of *who* to conduct the waste audit while 5.1.2 describes the different procedures of *how* to obtain different categories of waste data.

5.1 Manual Method

5.1.1 Human Resource

This section discusses the question of *who* to conduct the manual waste audit. Our group looked at a few other universities that have conducted waste audits. In 1997 and 1998, a one-time waste audit was conducted in the University of Waterloo by a group of students, as part of a 'Management Sciences' and 'Environmental Studies' course (Lampi, 2011). Dalhousie University also conducted waste audits using staff and student volunteers (Dalhousie, 2011) Our project will consider using students studying courses related to sustainability or environmental studies to carry out these waste audits.

Similar one-time waste audits were also conducted in UBC (MJ Waste Solutions, 2010) and McMaster University (Hall, 2011) in 2009 and 2011 respectively, but by external auditors. However, the stakeholders have reflected that this hiring of external auditors was expensive. Hence we postulate that this method is most likely unsuitable for this project's context of a regular waste audit method, and will not be factored into our triple-bottom line analysis.

Apart from the above-mentioned method of using students to conduct the waste audit, we also suggest an alternative: integrating the waste auditing procedures described in Section 5.1.2 into the regular waste collection schedules, and using the currently employed custodial staff to carry out these audits. We believe that minimal amount of training would need to be provided as the data collection methods in 5.1.2 are fairly simple, and can be carried out in tandem with existing waste collection procedures.

5.1.2 Manual Auditing Methods

This section outlines the procedures to collect various categories of waste data in the new SUB. The categories are amount of waste, types/composition of waste, waste disposal rates and chemical data. We believe these categories of data will be useful to help set targets for waste reduction. These detailed procedures also provide the option to carry out waste audits at different levels of detail. Furthermore, they identify the constituents of waste for managing purpose. Algorithms, scheduling procedures and the technological components required are discussed as well.

5.1.2a Amount of Waste—Weighing

The typical method of measuring the quantity of waste is to weigh each waste bag from each bin (Ontario Ministry of the Environment, 2008). Here, we suggest that a digital weighing scale be installed into the custodial staff's collecting carts, such that they can weigh each bag during collection and record the data and location for data analysis. The advantage of using the custodial staff to record the data is that this procedure involves a minimal amount of extra work and training, and thus can be integrated into daily waste collection schedules.

A digital weighing scale can be assembled and built with the purchase of different parts (e.g. Load Cell, Analog to Digital Converter, Low-Pass-Filter, 8x1 LCD, etc.). A prototype circuit schematic is attached in Appendix A.

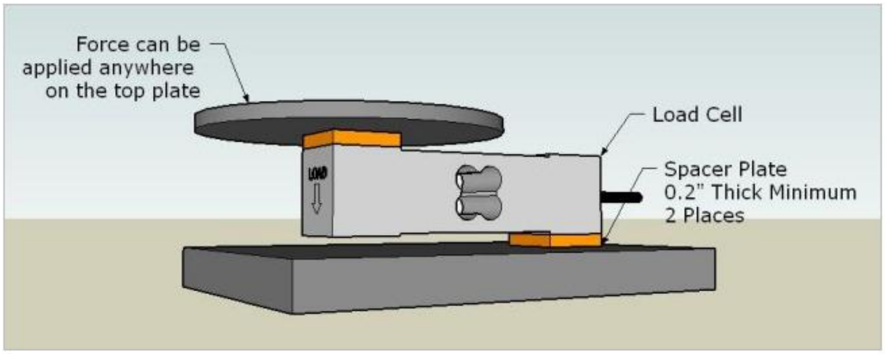


Figure 1 Basic design of Weighing Scale (Load Cell Central, n.d.)

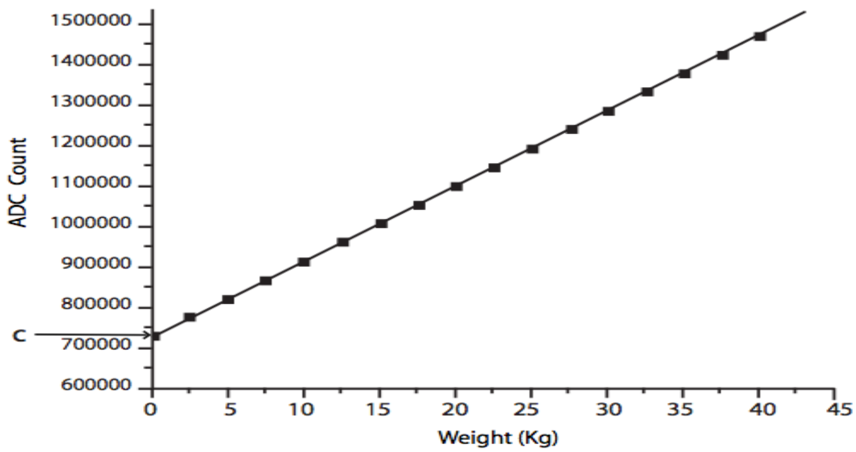


Figure 2 Load Cell Linear Characteristics

5.1.2b Types/Composition of Waste Materials—Sampling

In the old SUB, we observed that there are a various types of waste bins (General, Recyclable, Paper Products, Cans/Bottles, Compost). The previous algorithm in 5.1.1a provides raw data of the weight in each container. We cannot take this data as an accurate reflection of the amount of each type of waste without assuming that students dispose of their trash into the correct bins. However this assumption is not always valid. Therefore, we suggest two physical sampling methods to measure the composition of materials in the waste bags. Both methods sample 10% of waste in a bin each time.

The first sampling method is called "Systematic Random Sampling ". The location and time for sampling is randomly chosen using an algorithm that provides a random numbers table. The advantage of this algorithm is that it prevents the introduction of any potential bias. After the locations and times are chosen, the auditing team then performs samplings at regular intervals (for instance, every two hours) within a single day, recording the different types of waste in each bin. The resulting data obtained is an objectively measured, average composition of materials in each bin.

The second sampling method is called "Stratified Random Sampling". This type of algorithm provides a better average level sampling than the Systematic Random Sampling. The idea is to treat different layers of information as separated entities and establish a randomized sampling pattern. This suggests we can treat both locations and schedules as separated numbers and randomly choose one to perform a sampling.

As the summary of these algorithms, both algorithms can be operated in two different ways: *grab* and *composite* sample. A grab sample represents discrete information at a point with static conditions, while a composite sample involves obtaining an average concentration over an area or time period with multiple grab samples.

5.1.2c Waste Disposal Rates—IR Sensor and Automated Data Collecting

In the case of the above two methods, it is difficult to accurately derive, from the raw data, the variations of the waste stream according to time. Even with regular waste collection schedules (an hourly schedule for example), it seems to be a laborious task to collect hourly data of waste volumes just to be able to obtain a data plot of waste volume against time.

Hence we propose this method of using infrared (IR) sensors to obtain data on rates of waste disposal. IR sensor technology is considered because of its low cost and high reliability. An IR emitter and sensor is built into each bin, as shown in Figure 3. When the waste reaches the level of the IR sensor, the sensor will, through a wireless device built into the container, send a signal to the main server (an RF Module such as XBee®). Most of information is sent and received automatically, merely requiring the auditor to obtain the data collected in the server; therefore, this is an efficient way to audit waste. The design of the IR emitter and receiver would be based on information such as that in Figure 4.

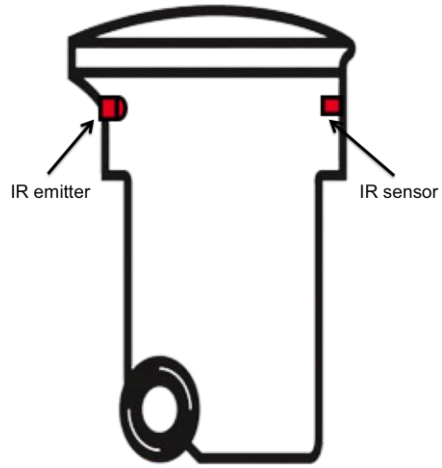


Figure 3 Illustration of IR emitter and sensor placing in trashcan

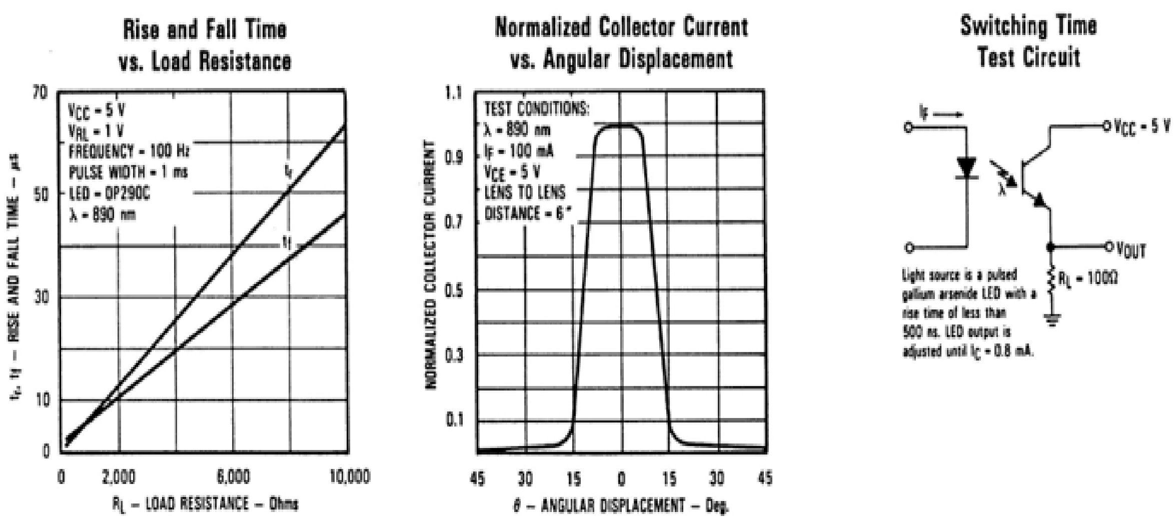


Figure 4 Graphs of Switching Timing and Sensitivity of IR Receiver

However, there are two major concerns present: the communication between each bin to the central server and the amount of E-waste that this technology can produce. This is covered in more detail under Section 6.1.

5.1.2d Chemical composition

While this project's main focus is in auditing *solid* waste, there exists a small but unavoidable amount of aqueous waste in most bins, more so in compost bins. This type of waste can be audited by applying chemical measurement. Two main factors are measured: pH and oxygen level. By measuring these levels, the auditing team will have better understanding of the environmental impact and help management to set targets for waste reduction.

5.2 Mechanized Method

This section describes the mechanized solution to UBC new SUB Solid Waste Accounting project. This section outlines the objective, process and theory behind the mechanized waste auditing solution.

The ultimate objective of conducting the waste audit is to improve waste management accuracy and efficiency. With the current waste management system, fifty-six percent of waste collected on campus is landfilled. (UBC Waste Management Department data collection, 2009-10) However, 2010 Waste Audit results show that fifty-one percent out of fifty-six percent landfilled material is recyclable (Figure 5)

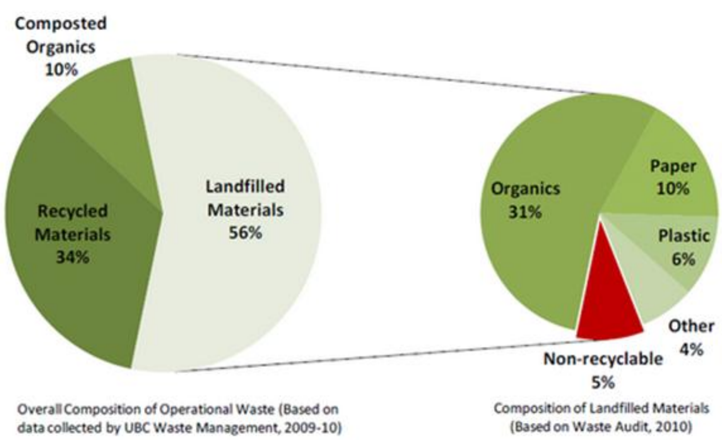


Figure 5 Waste Audit Result Pie Chart (UBC Waste Action Plan website)

The core technology associated with the mechanized solution is sorting technology. By first sorting waste generated from the new SUB into different types, and subsequently measuring each fraction's amount, the AMS would be able to obtain primary data on solid waste auditing and to improve the current waste management system. The ultimate vision of this project—a zero waste campus—can be achieved by analyzing types and amount of waste produced in the new SUB building and reduce particular types of waste subsequently.

5.2.1 Mechanized Process Description

For this mechanized solution, we investigated the sorting machines from the industrial sorting expert company—TITECH. The "TITECH x-tract" is a multifunctional sorting system that recovers a wide range of pieces of material from different waste streams: PVC, metals, stones, mixed plastic, packaging, paper etc. The most outstanding feature is that it produces a clean organic fraction and a clean non-organic fraction stream for landfill, which fulfills the ultimate objective of the waste audit.

Materials from different waste streams will be fed into TITECH x-tract machine through Point 1 shown on Figure 6. An X-ray source will emit X-rays through the waste material and an X-ray camera located at Point 2 will process and identify the types of material passing through, to decide which chamber (Point 4) does each piece of waste material go into. This process is further explained in Section 5.2.2. At the end of conveyer belt, air jets receive signals from the X-ray camera and inject high-pressure airflows to separate the waste into the right chamber. The weight of each category of waste can then be measured and fed into a database.

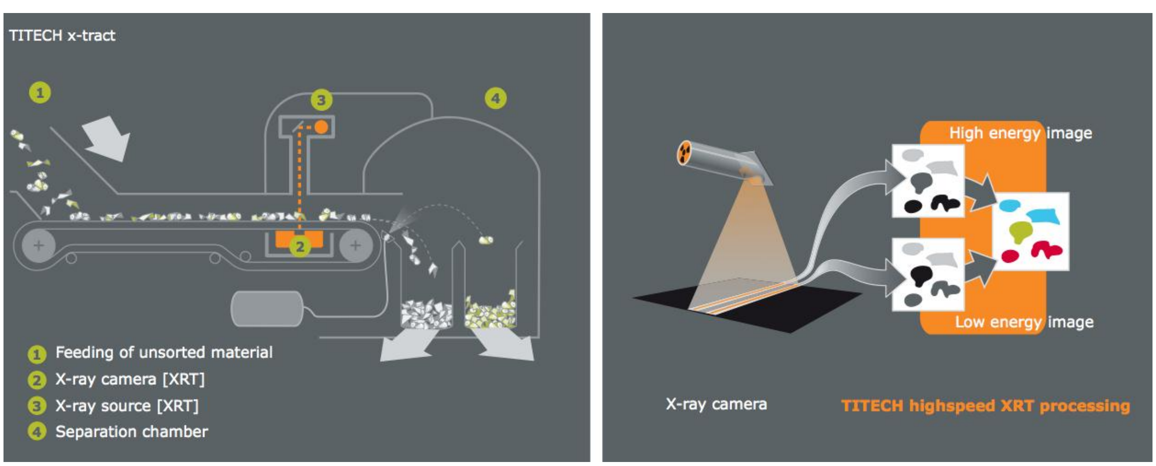
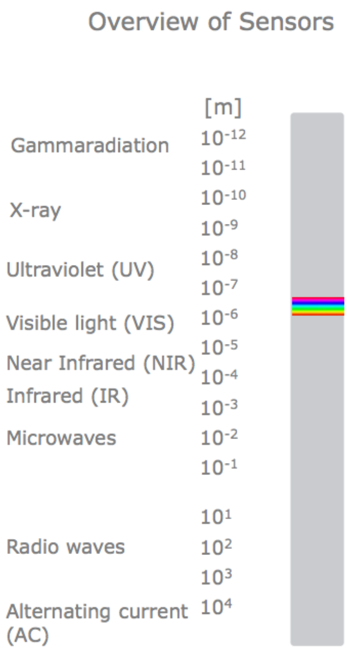


Figure 6 Overview of sorting machine (Titech, 2012)

5.2.2 Sensor Technology

Sensors are widely used devices for detecting physical property of objects. In this case, sensors will be used to detect material type, color, conductivity, permeability, and heat conductivity etc. Figure 7 describes the current sensors technologies currently available in the industry



Sensor/Technology	Material Property	Segment
RM (Radiometric)	Natural Gamma Radiation	Fuel, Precious Metals
XRT (X-ray transmission)	Atomic Density	Base Metals Precious Metals Industrial Minerals Fuel, Diamonds
XRL (X-ray Luminescence)	Visible Luminescence under X-rays	Diamonds
COLOR (CCD Color Camera)	Reflection, Absorption, Transmission	Base Metals Precious Metals Industrial Minerals Diamonds
PM (Photometric)	Monochromatic Reflection/Absorption	Industrial Minerals Diamonds
NIR (Near Infrared Spectrometry)*	Reflection, Absorption	Base metals Industrial Minerals
IR (Infrared cam)*	Heat conductivity, heat dissipation	Base Metals Industrial Minerals
EM (Electro-Magnetic sensor)	Conductivity, permeability	Base Metals

Figure 7 Overview of Sensors

In the machine we are considering, two major sensor technologies are used: X-ray Transmission (XRF) and X-ray Fluorescence (XRF).

The machine uses an electric X-ray source (Fig 2 Point 3), which creates a broad-band radiation. This radiation penetrates the unsorted waste and hits an X-ray camera containing a built-in sensor with two independent sensor lines with different spectral sensitivity. The data supplied by this camera is classified using high speed X-ray processing. As a result, the atomic density of the material can be identified, regardless of the material thickness.

X-ray fluorescence allows, for the first time, the detection of existing elements of particles. The material will be excited by low-energy X-ray radiation and element specific fluorescence will be released. With an energy dispersive X-ray sensor, the presence of different elements and their concentrations can be recorded.. This information, combined with additional data from an EM sensor using SUPPIXX® technology identifies the position and size of the object – and the set of air jets eject it precisely.

Other common sensor technologies such as EM and COLOR sensors are also commonly used for sorting machines. EM sensors identify the finest conductive particles in a flow of bulk solids. The image processing enhances the resolution of the digitalized sensor signals. The EM sensor is available in two resolutions: 25mm and 12.5mm coil diameter. These sensors can detect metal objects to a minimum size of 1-2 millimeters. Thus it is possible to identify the position of such fine particles in the waste stream with great precision and subsequently divert more recyclable material away from the landfill. With color cameras, the high spatial resolution in conjunction with precise color measurement enables sorting complex material streams of used electrical devices and the recovery of nonferrous metals with a high purity, which gives more accurate audit results.

5.0 Triple Bottom Line Assessment

6.1 Manual Method

In our triple bottom line analysis of the manual method, we looked at the manual method as one single method, while keeping in mind that the audits can be carried out by students and by staff.

6.1.1 Social

The manual method of waste auditing requires that the staff/students be trained to carry out the various auditing procedures, and to record the data in a proper format. Nevertheless, to repeat a previous point, we believe that the data collection methods detailed in Section 5.1.2 are fairly easy to implement.

There are safety and health concerns with the handling of waste during waste auditing, especially when handling waste in the compost bins. However, this can easily be overcome with proper safety protocol in handling waste (e.g. wearing gloves, protective clothing, goggles etc.)

Additionally, using students to carry out the waste audits can bring unique social benefits. Having a hands-on experience of carrying out the waste audit can increase students' awareness of UBC's efforts in sustainability. This will also complement students' learning in sustainability/environmental studies courses, and help them understand the challenges of waste management as well as the state of our waste disposal habits. However there may be difficulties in integrating such an activity into UBC courses, including overcoming students' unwillingness to handle waste, and instructors' willingness to integrate this hands-on activity into their courses.

6.1.2 Economic

The economic impact of the manual methods can be evaluated by considering the cost of such a method.

Firstly, we consider the cost of the technological equipment used in this method. The rough estimated unit cost of a digital weighing scale is between $\$34.643 \text{ to } 64.643 \pm \text{utility cost}$, (refer to a for cost breakdown) where utility costs include low cost consumables such as wires, capacitors, resistors, and material, etc. If we were to build the digital weighing scale ourselves (i.e. as a Electrical Engineering student project), the weighing scales can be manufactured at higher accuracies (e.g. at an uncertainty of 10g) and lower costs. Considering the fact that students are involved in designing and producing the weighing scales, and that they can reuse/recycle components from previous projects, the cost of each weighing scale can be lowered drastically. Nevertheless, there needs to be further discussion with the Electrical Engineering Department.

As for the infrared sensor and emitter, the total cost of these items ultimately depends on the design of the circuit diagram. These are our estimations of the individual cost for a single unit of: XBee® wireless RF module=$36.00, infrared sensor and emitter=$3.00, operational amplifiers=$2.00 and some consumables=$10.00. The cost of the server or wireless RF module requires further analysis, as a preliminary online search seems to indicate that there are cheaper alternatives in the market.

Next, with regards to employee and technician wages, payroll expense should remain the same during the implementation of the manual method. However, some additional labor will be required to organize and process the data obtained electronically or on paper. Nevertheless, this will be the same for the mechanized method.

6.1.3 Environmental

In our last assessment, we narrow down our analysis into two areas of environmental law: clean tech and waste. Environmental law describes operations that regulate the interaction of humanity and the environment, where clean tech law includes technologies in sectors: energy, materials, transportation and waste law includes treatment, storage, disposal, and recycle of waste.

In terms clean technology, the electrical power consumption of the IR sensor and wireless transmission is low because the electrical components should be in power-saving mode for most of the time when not in use/when not transmitting. Similarly the electrical power consumption of the digital weighing scale should be very low, as it only gets switched on during waste audits and even then, it consumes a very low amount of power.

The environmental footprint in the manufacturing of these devices ultimately depends on the design. If recycled materials are used and the design includes a high level of reparability, then the environmental footprint will be low.

Finally, every piece of technology produces a certain amount of e-waste. The disposal of any malfunctioning component will contribute to e-waste. However, if disposed properly (e.g.

through UBC Waste Management's e-waste drop-off), this e-waste will not cause any significant environmental impact.

6.2 Mechanized Method

6.2.1 Social

Although the cost of currently available machines are prohibitively high, UBC could consider working with these waste sorting companies to create a pilot machine, at a smaller scale and cheaper cost. If this venture proves to be successful, this mechanized method of sorting waste could be shared with and replicated in other campuses, raising awareness of UBC's efforts to strive towards sustainability, potentially inspiring the managements of other industrial or commercial buildings to consider adopting similar methods.

This solution could also increase awareness of UBC's sustainability efforts in the industrial arena, positioning UBC as a potential partner for companies' sustainability efforts. Also since it is a fairly automated solution, it will require fewer man-hours, compared to the manual solution, to conduct a waste audit. However, there may be a need to provide custodial staff with the necessary training to operate the machine.

6.2.2 Economic

This section outlines the economic evaluation of the project in terms of upfront capital cost, operating and maintenance costs perspectives.

The mechanized solution is not the most cost effective methodology for waste auditing. Capital investment on mechanized solution is significantly larger according to the data quoted by the vendor (i.e. TITECH). The smallest waste sorting machine unit is estimated to be $700,000 (personal communication, October 15, 2012). Additionally, current machines are designed to accommodate large volumes waste treatment. In the context of the new SUB, the waste materials generated are far less than the material handling capacity. Therefore, the equipment usage is not maximized. Power consumption for the various equipment sizes are shown on Figure 8. The smallest power consumption is 9.1 KW, which is 36.4 KWh for a 4-hour operating day. This translates into electrical power consumption, which adds to the operating cost.

Machine Tag	XRT x-tract 600	XRT x-tract 1200	XRF x-tract 1200	XRF x-tract 1800	XRF x-tract 2400
Power Consumption	9.1 KW	9.1 KW	17 KW	17 KW	17 KW

Figure 8 Power Consumption Rate (Titech, 2012)

There are also maintenance considerations. Dirt, wear and damage lead to a decrease in sorting performance; and that cuts into the efficiency and accuracy of sorting wastes. It is therefore necessary to keep the output of the sorting system as high as possible and the leftover waste for disposal as low as possible. The best way to guarantee this is regular care and maintenance. The SUB staff can carry out basic maintenance easily, after going through some simple safety training, which is provided by the vendor company. This reduces the cost of hiring external specialists. However, in the field of highly sensitive measuring technology, expert knowledge is indispensible. According to the vendor's data, the cost of hiring specialists is estimated to be one per cent of revenue generated from recyclable materials.

6.2.3 Environmental

The most significant environmental benefit is the fact that in the process of accounting for waste, the waste is also sorted according to its material type. Hence recyclable waste that was originally headed for the landfill is now diverted to the right avenues for disposal (recycling, composting etc.), which according to Figure 5 accounts for 95% of pre-sorted landfill waste. This is in-line with UBC's ultimate zero-waste goal under the Climate Action Plan. However, the sorting machine does consume a significant amount of electricity. As mentioned in the Economic analysis, the machine has a power rating of 36kWh for a 4-hour operating day. Nevertheless, keep in mind that this machine is a large capacity machine, capable of processing high volumes of waste.

6.0 Recommendations

This section outlines the recommendations that were formed from the triple bottom line assessment. Recommendations are suggested based on the short term and long term perspective. The 'short-term' is set as the next 2 to 3 years, while the 'long-term' refers to the 3rd year onwards.

7.1 Short Term

The manual methodology is recommended for short-term purposes. As the new SUB begins its operations, it is important to utilize a straightforward, affordable, reliable, low risk method. The manual methods used in an effective way can also be seen as a way to promote sustainability within the student body and among faculty members. Several easy techniques can be implemented to maximize the accounting result, as well as waste awareness.

It is suggested that placing sorting bins in various locations of the new SUB to segregate paper products, cans, bottles and compose materials. Since infrared technologies are a cheap and efficient way to collect data on waste disposal rates and relatively cheap to install, we recommend having these sensors installed at various levels of the bins to provide more accurate notifications of the waste level, thus incorporating waste tracking abilities right into the recycle/trash-bins.

We also recommend further discussions with Department of Electrical and Computer Engineering regarding the feasibility of implementing the design and manufacturing of the required electrical components (infrared sensor, weighing scale) as student projects.

To minimize the overall waste auditing budget and increase waste awareness in UBC, we also suggest promoting waste awareness on campus, especially within courses related to sustainability, technology and the environment. To increase students' involvement and awareness, waste audits can be organized as a project or assignment for such courses. However, there needs to be further discussion with the various course coordinators. We also suggest looking into recruiting student job seekers (under the Work Study/Work Learn program) or volunteers to conduct these waste audits, to further promote waste awareness.

For accounting accuracy, and to improve future auditing methods, still recommend engaging third party companies to do detailed waste auditing for the SUB periodically. The data and results obtained from the detail audit can be used to evaluate the accuracy of and improve on the new SUB's own manual auditing methods.

7.2 Long Term

UBC has the ultimate vision of being a waste free campus. As mentioned previously in the report, more than 90% of the landfill waste can be recycled with the presence of advanced technology. Waste sorting technology can help UBC achieve that ultimate vision while fulfilling the requirements of this project.

Sorting technology currently is expensive and not energy efficient to due to the limited sizes available. Even the smallest machines are overly large for the new SUB. However, if there are ways to reduce the machine sizes by negotiating with the vendor or increase the scope of waste accounting to include other buildings around the new SUB too, sorting machines could potentially be a very viable and innovative solution for solid waste accounting.

The first step we recommend is to investigate further into the different local companies specializing in waste sorting and seek for opportunities to reduce the machine size down to a smaller sized pilot machine and the to rent, lease or test a machine for campus waste auditing. If sorting and auditing test results are substantially more accurate and efficient than traditional methods, the technology may be expanded on a larger scale to benefit other buildings, campuses, and organizations or even on a citywide scale. The mechanized solution not only provides more accurate results, but it may also reduce the labor required in the waste sector, as well as offer new market opportunities, sorting solutions and partnerships among sorting companies and other organizations, maximizing the impact in the society while striving together towards establishing a waste free society.

7.0 Conclusion

We have outlined a manual and mechanized method of waste auditing for the new SUB. A triple bottom line assessment indicates that the manual method is more suitable for the stakeholder's current needs, mainly because it is the most cost-effective solution, and has many opportunities for student involvement, which we believe is crucial to raise awareness of UBC's sustainability efforts. The report also suggests the mechanized solution for the long term, however more research needs to be done to further confirm the feasibility of this solution. We hope that the specific waste auditing procedures outlined will be useful in conducting waste auditing in the SUB.

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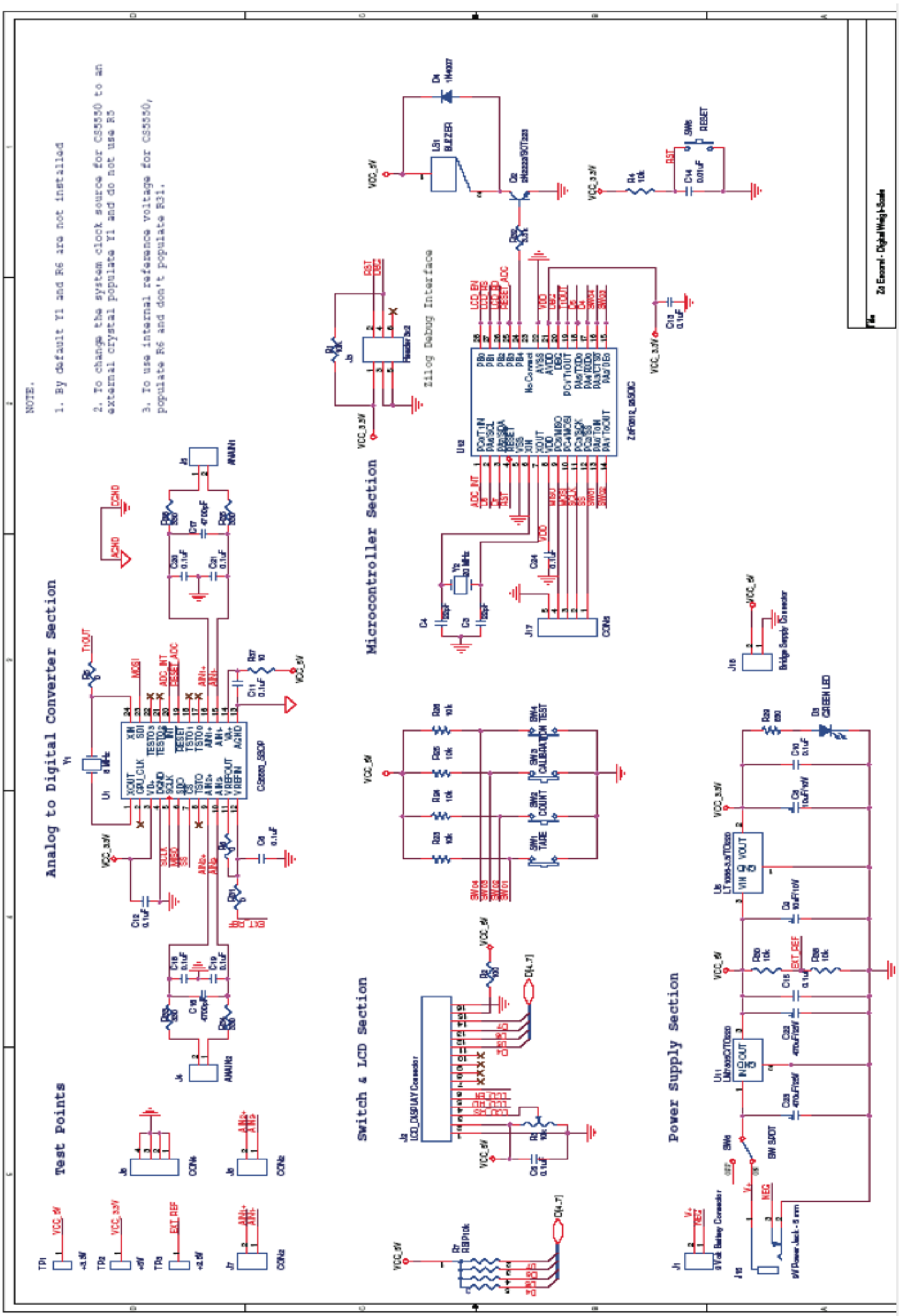
Appendix A: Electrical Circuits for Digital Waste Scale.



Appendix B Cost Breakdown of Weighing Scale components

Products	Parts No.	Reference	UnitCost (CDN)	Min. Quantity
Analog to Digital Converter (ADC)	598-1119-5-ND	Digikey	3.15500	100
Low Pass Filter (LPF)	LTC1560-1CS8#PBF-ND	DigiKey	4.8500	100
Z8 Encores! MCU	269-4277-ND	Digikey	4.0100	100
LCD 8x1	153-1113-ND	Digikey	2.6280	100
Load Cell	N/A	N/A	20 to 50	1