

Wireless Garbage Bin Sensor Project

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University of British Columbia

VOL 400

May 29, 2017

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Student Consulting Group

(Albert Kong, Amanda Santoro, Jennifer Ongko, Juliana Hamada, Scott Erickson)

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Executive Summary

UBC Waste Management currently follows a fixed route when collecting garbage from bins and compactors around campus. This leads to inefficiencies as bins that are only partially full (or even empty) will also be emptied during each trip. To improve campus waste operations, there is value in monitoring waste levels in each bin and the different waste outputs from each building. With this information, garbage truck routes can be optimized, different engagement groups around campus can be informed, and UBC's Zero Waste Action Plan can be better executed.

In this project, our group investigated the possibility of implementing a waste monitoring system for the UBC Vancouver campus. Specifically we looked at different network and sensor technologies provided by Internet of Things (IoT) companies around the world. Through our research we came up with three viable network technologies that can be implemented; LoRa, Zigbee, as well as standard cellular connections, each with multiple compatible sensor options.

We contacted numerous companies and requested quotations for the sensors and services they provide. The values we obtain come with the assumption that a total of 115 dumpsters will be monitored, spread evenly in a 4 km² area. When available, we also included information and quotation for 10 compactors. We then compared the different sensor options; mostly in terms of costs though additional features such as ease of maintenance, scalability, and reliability are considered.

After carefully considering all networks and sensor options, we concluded that buying Sensoneo sensors with a LoRa network is the most optimal solution for UBC. This option was the most cost efficient both in terms of initial costs as well as ongoing costs. Furthermore, other aspects such as ease of implementation and maintenance, reliability, functional life and scalability were also considered, and Sensoneo performed very competitively in all these aspects. In this report we will elaborate further on our conclusion; explaining the method we used to measure and compare solutions.

Note that our research is restricted to sensors and networks that can be or are deployed in Canada and in no way is our list exhaustive. We also did not thoroughly investigate the possibility for UBC to develop their own solution as this would fall outside the scope of our

project. Nevertheless we would strongly encourage UBC and SEEDs to consider the results of our investigation as we believe that an extensive catalog of companies has been surveyed and that our conclusions will prove to be beneficial to UBC's decision to implement the sensor/network solution.

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Introduction

Problem Description

UBC Waste Management is interested in tracking the quantity of garbage produced in each building on campus. The current method for garbage collection only allow for the *total* amount of campus waste to be monitored, since garbage from all dumpsters is collected by a single truck, hauled to the landfill transfer station, and weighed at the station. UBC has looked at Enevo, a sensor technology that uses cellular networks to transmit information. However, there is a steep monthly fee associated with the cellular connection. Hence, UBC is interested in investigating alternative, wireless technologies for waste monitoring, including technologies that require outdoor IoT networks like Sigfox and Zigbee to be installed. UBC is interested in knowing if such solutions would have a lower cost than using cellphone network based sensor technologies.

Scope Definition

Within this project we investigate the viability of implementing an internet of things (IoT) based waste management system to the UBC Vancouver campus. Though our team has surveyed and prepared an expansive list of options, it is by no means exhaustive. We also restricted our efforts to comparing subscription based solutions, and did not investigate the possibility of UBC developing its own technology to address the problem. Our comparisons are also mostly based on cost and ease of implementation, we did not attempt to forecast potential savings from adapting one solution over another.

Available Solutions

In the sections that follow, the investigated solutions will be presented and compared. In our search we found three main types of networks most commonly used by solutions: Cellular, LoRa and Zigbee. A more detailed explanation on their functioning as well as the sensors that are compatible with each network will be displayed. Finally, by considering the fixed and running costs of each option as well as additional factors such as ease of implementation, we present our recommended solution.

LoRa Network Based Solutions

With LoRa network based solutions, each bin sensor sends data to a router like device, called LoRa gateway using radio frequency (RF) waves. A single gateway can cover an area of hundreds of square kilometers, depending on the degree of obstruction in the environment. Depending on the sensors and the desired applications, data can be sent to the server continuously or in short bursts, optimizing energy consumption. One of the benefits of using a LoRa network is that there is no need to connect a sensor to a specific LoRa gateway. Data sent by a sensor can be received by multiple gateways that are in range. Upon receiving data from sensors, each of the gateway will forward data to LoRa cloud server. LoRa gateways can be connected to the cloud server either by cellular, ethernet, WiFi, or satellite connection. Data uploaded to the cloud server can then be downloaded by users into their PCs or mobile devices either through a specific website or through an application provided by the sensor companies.

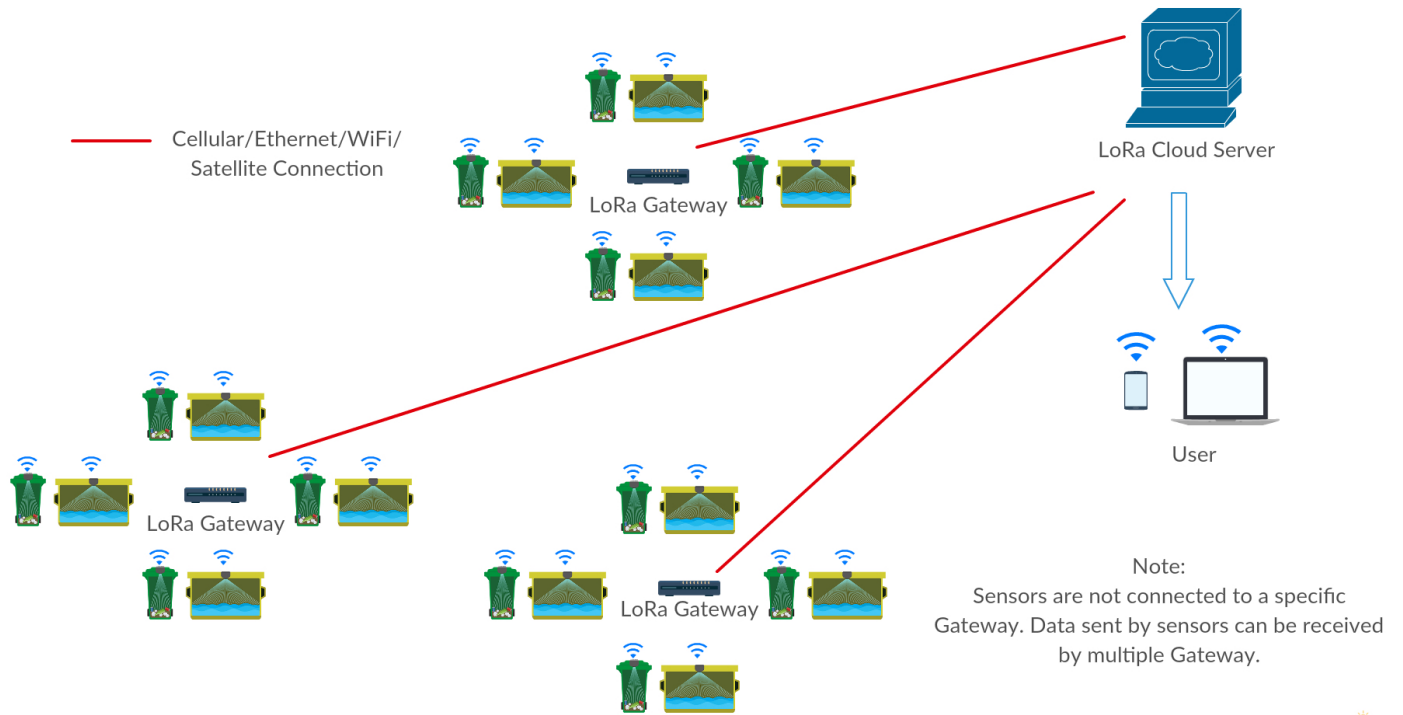


Figure 1: Framework of LoRa Network Based Solutions

Available Sensors for LoRa Networks

There are a few companies that currently offer LoRa network based bin sensors. These companies offer a selection of services such as: sensor rental or purchase, software (data analysis - eg. route optimization and user interface), installation, and maintenance. The list of the companies is provided below.

- IoTsens
- Sensoneo
- WMW
- SmartBin

Cellular Network Based Solutions

With cellular based solutions, each sensor (in each bin) sends data directly to the server where it is processed and monitored. Because of this direct communication feature, cellular based solutions have no limitations in range. However, the effectiveness of cellular solutions do depend on the quality of network present at UBC.

All companies who provide cellular based solutions include a professionally designed user interface with their service. Generally their services include a multitude of additional features such as route optimization, GPS and accelerometer functions, and additional data collection features (such as temperature monitoring). Furthermore, these companies have close ties with major cellular network providers so implementation of the solution is greatly simplified.

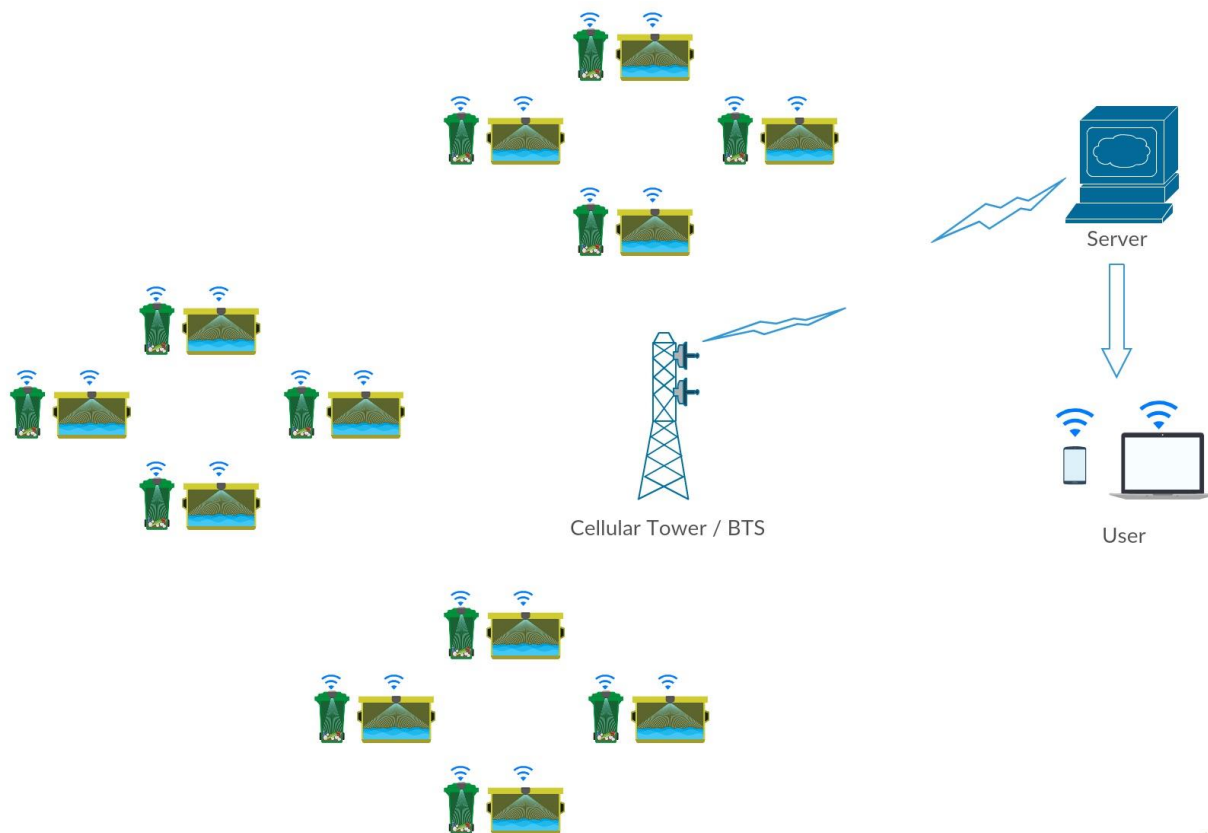


Figure 2: Framework of Cellular Network Based Solutions

Available Sensors for Cellular Networks

There are a few companies that currently offer cellular network based bin sensors. These companies offer a selection of services such as: sensor rental or purchase, software (data analysis - eg. route optimization and user interface), installation, maintenance. A list of the companies is provided below.

- IoTsens
- Compology
- eCube Labs
- Nordsense
- SmartBin
- Recycle Smart

Zigbee Network Based Solutions

With Zigbee network based solutions, each bin sensor sends data to a Zigbee router using RF (radio frequency) waves. The sensors must be within 10-100m of the router's line-of-sight, but the actual distance depends on possible obstructions present in the environment. Each of the routers will, then, forward the sensor's data to a zigbee coordinator using RF waves. The Zigbee coordinator will, in turn, send data to the server through a **wired connection** to one of UBC's central computers. Finally, users can download the data from the server into their PCs or mobile devices either through a specific website or through an application provided by the bin sensor companies.

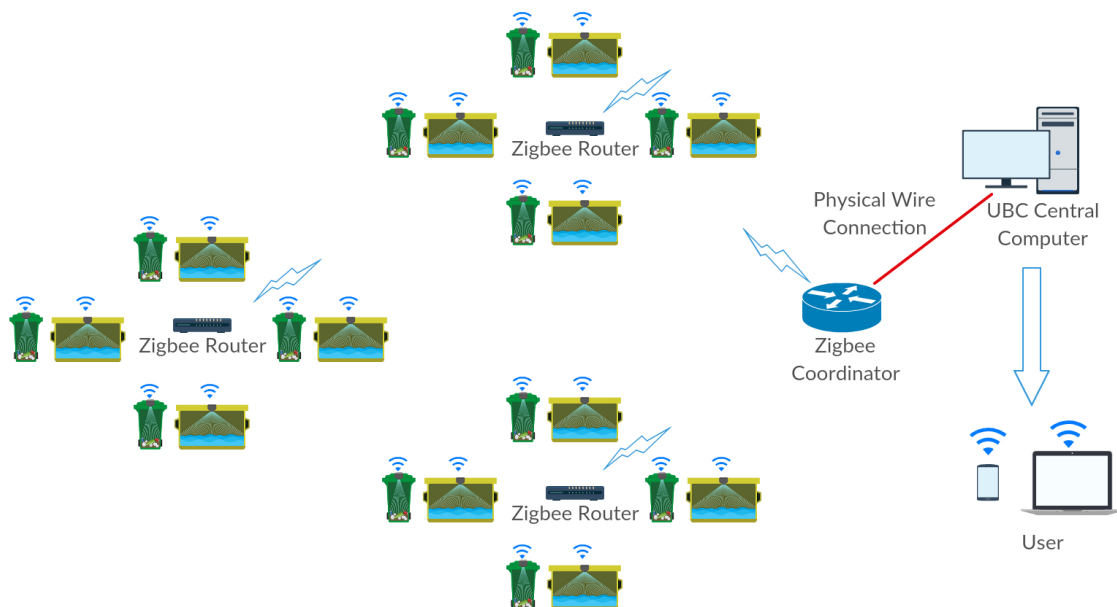


Figure 3: Framework of Zigbee Network Based Solutions

Available Sensors for Zigbee Networks

Note in the previous figure that only one coordinator is allowed for each network in Zigbee systems. Through our research we came to the conclusion that Zigbee is inferior to both LoRa and cellular networks. We found that many companies who do offer Zigbee based solutions do not deploy their services to Canada. Furthermore, companies that do claim to deploy to Canada, failed to respond to our inquiries.

As a result, in further sections of this report we will not discuss Zigbee based solutions further. We will concentrate on companies working in LoRa and Cellular networks and present our comparison of these companies' services.

Compatible Sensors and Networks

The following figure describes and summarizes the list of companies we have investigated and the network(s) they work with. Note that only companies who have replied to our queries will be included in the diagram, as many companies who we contacted did not reply or actually do not provide their services to Canada.

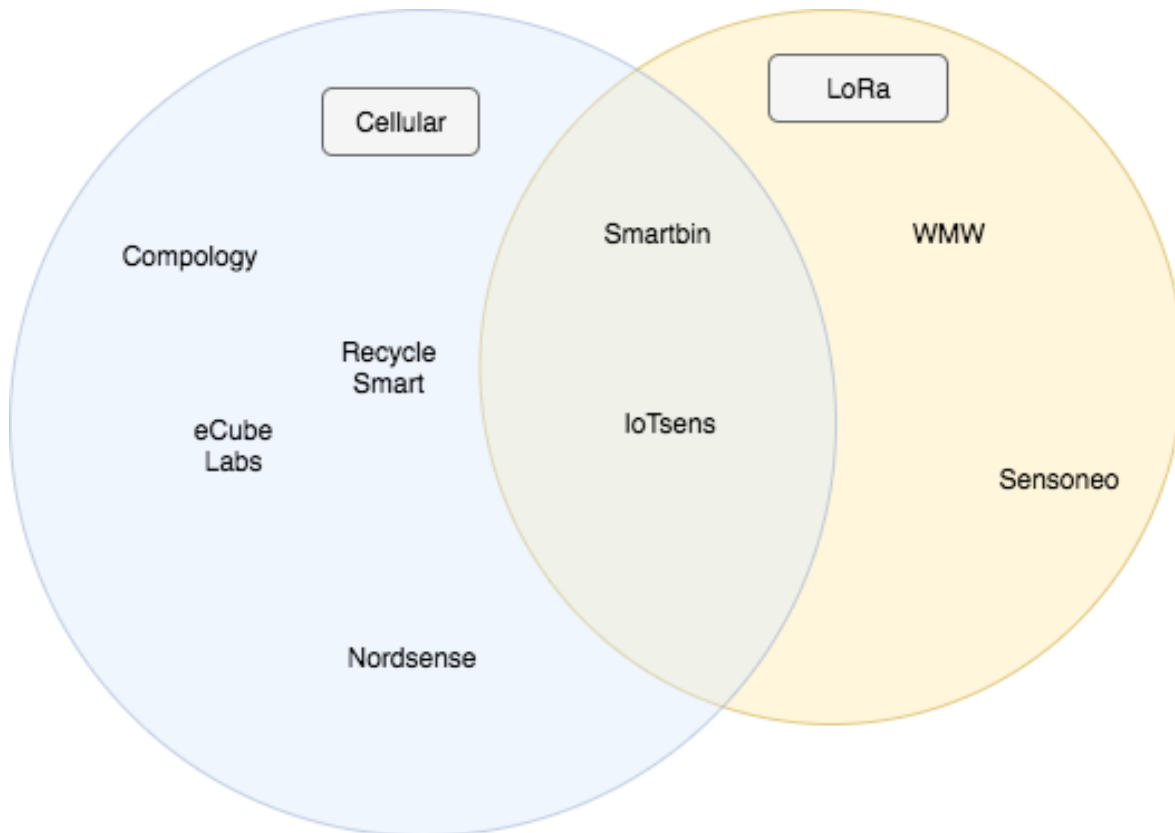


Figure 4: Investigated IoT Waste Monitoring Solutions

In the following section, we will discuss the aforementioned companies in further detail. Specifically we will outline the different services they provide (i.e. rental of cellular sensors and sale of LoRa sensors), the costs of each service and the different features that are included. Please note that **all listed prices do not include tax and shipping**. Also note that for sensors that are compatible with **compactors**, installation of these sensors **might** void the compactors' warranty as drilling into the compactors is often required. UBC should clarify this before purchasing sensors for the compactors.

All companies we contacted provide (at the very least) online tech support for their sensors/services. Some companies are able to give higher level support such as in person

maintenance or repair services but this is less common and only applies to companies that are local to British Columbia.

To aid in our comparison, we will post quoted costs of each sensor in their base currency as well as in CAD. The currency conversion rate used in the following section is the rate obtained on April 13, 2017. The table below shows the conversion rate that were used:

Table 1: Currency Conversion Rate

Foreign - CAD	Rate
USD - CAD	1.38
EUR - CAD	1.41

To accompany our report, we will also include documents that the companies have provided us. They will include more details regarding the different features each company offer and will generally be useful in case certain values or details need referencing.

Recycle Smart

This company is located in Richmond, BC, Canada and offers a full service: hardware, hardware installation and user interface managed by the company. They sell sensors from a company called Enevo which uses cellular networks. One advantage of choosing Recycle Smart would be fast customer service, no need to install a network since it connects to cellular networks, and short term competitive prices (i.e. cheap fixed costs). Recycle Smart has been working with this type of technology for approximately 5 years, and other applications for the sensors would be monitoring oil levels in tanks.

The following table summarizes Recycle Smart's services:

Table 2: Information on Recycle Smart Services

Recycle Smart	Dumpsters - Lease (115)	Compactors - Buy (10)
Fixed Costs (Hardware)	-	CAD 25,000.00
Installation	CAD 2,500.00	CAD 2,000.00
Monthly Fee	CAD 3,162.50	CAD 1,650.00
Features	<ul style="list-style-type: none"> ● Temperature ● Collection Date ● Fill Level ● Ultrasonic sensor 	
Shipping	Included	Included
Data Output	GUI, export to spreadsheet	GUI, export to spreadsheet
Notes	Quotation assumed a three year contract with Recycle Smart.	If UBC wishes to manage the compactor monitors the monthly fee would be \$650.00

WMW

WMW is an IoT company based in Hasselt, Belgium. Their waste management products include LoRa ultrasonic sensors that can work for more than 10 years without the need for battery change and software for users to access sensors' data. However, sensors will need to be replaced once they run out of battery.

When purchasing the sensors, users can choose to add fire detection and motion sensors and whether to purchase the sensors with the holder for mounting. Users can also choose whether to purchase the software or not (when users choose to purchase the software, there is a high one time cost for software setup and licensing; when software is not purchased, only raw/unprocessed data will be made accessible to user). However, WMW does not provide installation services. They do however, provide a manual for self-installation. The table below summarizes WMW's sensors and software.

Table 3: Information on WMW's Services

WMW	Dumpsters without software (115)	Dumpsters with software (115)
Fixed Costs (Hardware)	€12,995 (CAD 18,322.95)	€25,995 (CAD 36,652.95)
Installation	Self Installation	Self Installation
Monthly Fee	€230 (CAD 324.30)	€430 (CAD 606.30)
Features	<ul style="list-style-type: none"> ● Grouping of containers (marking by type) ● Collection Date ● Data history 	<ul style="list-style-type: none"> ● Grouping of containers (marking by type) ● Map of sensors ● Collection Date ● Data history
Shipping	Not Included	Not Included
Data Output	Raw data	Mobile app, Webapp
Notes	<ul style="list-style-type: none"> ● These prices don't include sensor holder (for mounting). Each holder costs €20 (CAD 28.20). ● Sensors update daily, but update time can be changed 	

Please note that compactor sensors and software has the same price as the price quoted in the table above. For the solution provided by WMW, prices highly depends on the quantity of sensors purchased by UBC. WMW will give a lower price for higher quantity.

SmartBin

SmartBin offers intelligent monitoring solutions for the waste management industry. They have company support centres in Dublin, Chicago and Sydney and partner networks worldwide. They do not provide installation of their devices, however they do provide periodic reports with updates and alerts when bins are full. SmartBin provides a network analysis to select the best one available to use for their sensors, between cellular networks, LoRa and Sigfox. Their services include cloud based applications, such as a mobile app, and API integration. The prices quoted here are rough estimates, since SmartBin requires the signing of an NDA before they can disclose accurate prices.

The table below summarized SmartBin's services for 115 sensors:

Table 4: Information on Smartbin's Services

SmartBin	Dumpsters (115)
Fixed Costs (Hardware)	USD 5,750 (CAD 7,935)
Installation	Self installation
Monthly Fee	USD 1,150 (CAD 1,587)
Features	<ul style="list-style-type: none"> ● Ultrasonic fill-level ● 10 years battery life ● Geolocation/GPS ● Temperature ● Tilt levels ● Route optimizations ● Non-corrosive protective shell
Shipping	Not Included
Data Output	UI, mobile app, integrated API
Notes	The monthly fee can range from USD 8 to USD 12 (CAD 11.04 to CAD 16.56) - Smartbin were not able to give hard values in their quotes because of their mandatory NDA policy.

SmartBin also provides sensors for waste and cooking oil, textiles and recycling bins.

Nordsense

Nordsense is based in Copenhagen, Denmark and they offer waste monitoring services through cellular network sensors. They have recently expanded their offices to California and are able to provide technical support if needed. Though they do not offer paid or free installation of their devices, they offer flexible data outputs and the option to analyse our data for us. They produce their own sensors which uses laser technology, claiming that this results in increased sensor reliability. Nordsense has plans to expand their services to include LoRa network solutions by 2018. They claim to be able to help UBC expand their IoT framework to LoRa solutions in the future when they have successfully expanded their services.

The following table summarizes Nordsense’s services for 115 dumpster sensors:

Table 5: Information on Nordsense’s Services

Nordsense	Dumpsters - Purchase (115)	Dumpsters - Lease (115)
Fixed Costs (Hardware)	USD 14,375 (CAD 19,837.5)	-
Installation	Self installation	Self installation
Monthly Fee	USD 460 (CAD 634.80)	USD 11,040 (CAD 15,235.2)
Features	<ul style="list-style-type: none"> ● Temperature ● Collection Date ● Fill Level ● Laser ● Adjustable sampling rate and fill thresholds ● Dynamic route optimization 	
Shipping	Not Included	Not Included
Data Output	GUI, user accessible, flexible data output	GUI, user accessible, flexible data output
Notes	Payment details: 1-year binding period starting 30 days after shipment. Thereafter monthly rates - paid annually.	

Nordsense includes a self installation guide with purchase of their services and they offer two different sensor sizes to cater to different bin sizes and each sensors has a predicted battery life of 5-10 years. Upon battery failure or drainage we would have to purchase new sensors to replace current ones, or they will send new sensors at no cost if we lease the sensors. Their UI also features a dynamic route optimization where if a bin becomes full while a truck is on pickup

rounds the truck will be notified. Nordsense’s sensors are also generally compatible with compactors, though this will depend on the compactor design.

Sensoneo

Sensoneo is a company based in Slovakia and they offer waste monitoring services through sensors that connect with 3 types of network - cellular, LoRa, and Sigfox. They do not provide installation services, but they include a self installation guide with the purchase or lease of their sensors and software. Sensoneo’s sensors use ultrasound technology and it has a lifespan of up to 8 years. However, sensors will need to be replaced once they run out of battery. Sensors are also water and shock resistant. Sensoneo’s software is available for PC and handheld devices (both Apple and Android devices). The table below summarizes the price for both the purchase and lease options of Sensoneo’s sensors and software.

Table 6: Information on Sensoneo’s Services

Sensoneo	Dumpsters - Purchase (115)	Dumpsters - Lease (115)
Fixed Costs (Hardware)	€18,285 (CAD 25,781.85)	-
Installation	Not Included	Not Included
Monthly Fee	€103.5 (CAD 145.935)	€563.5 (CAD 794.535)
Features	<ul style="list-style-type: none"> ● Approximate weight of waste in container ● Fill Level ● Route optimization ● Map with bins ● Statistics and trends 	
Shipping	Not Included	Not Included
Data Output	UI, mobile app	UI, mobile app
Notes	LoRa data cost not included.	Monthly fees include software and sensor lease, but not LoRa data cost.

eCube Labs

eCube Labs is a company based in Seoul and Los Angeles, but they have a distributor in Pickering, Ontario (EcoVision Environmental is the name of the distributor). The sensors that they sell use cellular networks and they use ultrasonic technology for sensing. Sensors typically lasts for up to 10 years and the software is accessible through the web and mobile application for both Android and iOS devices. However, sensors will need to be replaced once they run out of battery. If UBC decides to purchase eCube Labs' sensors, UBC can purchase them through EcoVision Environmental in Pickering, Ontario. However, sensors would need to be self-installed (the company will provide manual for self-installation). The table below summarizes the price for eCube Labs' sensors.

Table 7: Information on eCube Labs' Services

eCube Labs	Dumpsters - Purchase (115)
Fixed Costs (Hardware)	CAD 17,250.00
Installation	Not Included
Monthly Fee	CAD 2,300.00
Features	<ul style="list-style-type: none"> ● Fill level ● Route optimization ● Statistics and trends
Shipping	Not Included
Data Output	UI, Mobile App
Notes	Monthly fee would be reduced from CAD 20 to CAD 15 per dumpster for 48 month contract

Although the price above is quoted for dumpsters only, eCube Labs' sensors can actually be installed in compactors as well. In addition, eCube Labs also sells compactors that are already equipped with sensors.

Compology

Compology is an American company based in San Francisco, CA and offers a full service product that connects to cellular networks. Compology does all hardware installation and repairs. It also provides an app to its clients which tracks individual bin waste heights and provides a driver route optimization service. One of their first clients was the University of California Santa Cruz (UCSC) and they have been using Compology services for about three years now.

Table 8: Information on Compology's Services

Compology	Dumpsters - Lease (115)	Compactors - Lease (10)
Fixed Costs (Hardware)	-	-
Installation	USD 11,500 (CAD 15,870)	USD 1,000 (CAD 1,380)
Monthly Fee	USD 2,875 (CAD 3,967.5)	USD 250 (CAD 345)
Features	<ul style="list-style-type: none"> ● Temperature ● Collection Date ● Fill Level 	
Shipping	Included	Included
Data Output	GUI	GUI
Notes	Full service included with subscription. They will monitor and replace sensors as needed at no cost to UBC.	Full service included with subscription. They will monitor and replace sensors as needed at no cost to UBC.

IoTSENS

IoTSENS is an IoT company based in Spain and they sell waste height sensors along with software that can be used with the sensors. They offer both sensors that can work over the cellular and LoRa network. Their sensors use ultrasonic technology for sensing and their software is compatible for both PC and mobile devices. However, the company does not provide installation services. Upon purchase, IoTSENS will give a self-installation manual. The table below summarizes the price of IoTSENS' sensors and software. Note that all price listed in the following table **do not account for the discounts that they offer**.

Table 9: Information on IoTSENS's Services

IoTSENS	Dumpsters - purchase using LoRa (115)	Dumpster - purchase using Cellphone Network (115)	Compactors using LoRa (10)
Fixed Costs (Hardware)	€36,800 (CAD 51,888)	€33,925 (CAD 47,834.25)	€2450 (CAD 3,454.50)
Installation	Self Installation	Self Installation	Self Installation
Monthly Fee	€258.75 (CAD 364.84)	€546.25 (CAD 770.21)	€22.5 (CAD 31.73)
Features	<ul style="list-style-type: none"> ● Fill Level ● Truck Route Maps ● Temperature ● Collection Date ● Historical Analysis ● Download Info in Excel Spreadsheet 		
Shipping	Not Included	Not Included	Not Included
Data Output	GUI	GUI	GUI
Notes	<ul style="list-style-type: none"> ● 20% + 2.5% discount for hardware ● Monthly fee does not include LoRa data cost. 	<ul style="list-style-type: none"> ● 20% + 2.5% discount for hardware ● Fees include one-time SIM activation which costs €1.8 (CAD 2.54) and monthly GPRS data which costs €2.5 (CAD 3.525) per sensor. 	<ul style="list-style-type: none"> ● 20% discount for hardware ● Monthly fee does not include data cost

In addition to the sensors and software, IoTsens also sell their own LoRa gateway. Gateways sold by IoTsens have a range of up to 15 km and it can support thousands of devices so potentially, only one gateway is needed to cover the whole UBC area. The table below provides the cost of IoTsense's LoRa gateways.

Table 10: Information on IoTsense's LoRa Gateway

IoTsens	LoRa Gateway
Fixed Cost	€1,490 (CAD 2,100.9)
Monthly Fee	Depends on data; around €1.2 (CAD 1.7) per sensor per month (pay data cost directly to IoTsens)
Specifications and Requirements	<ul style="list-style-type: none"> ● Require Ethernet or 3G/4G connection to server ● OS: Linux ● 1 GB RAM, 16GB temporary storage, ARM Processor ● Requires permanent power (no battery) ● Frequency: 868MHz ● Sensitivity down to -138 dBm ● SX101 baseband processor ● Parallel demodulation paths ● 1 (G)FSK demodulator ● 2 x SX1257 Tx/Rx front-ends ● GPS receiver (optional) ● Range up to 15 km (Line of Sight); several km in urban environment

Feature Comparisons Across Services

The following figures summarizes the different features offered by each of the aforementioned companies.

Comparison of Lease Options

Features	Nordsense	Compology	RecycleSmart	Sensoneo
Software Included	✓	✓	✓	✓
Data Analytics	✓	✓	✓	✓
Raw Data Accessable	✓		✓	
Scalability	✓	✓	✓	✓
Company Install		✓	✓	
On Site Support		✓	✓	
Alerts / Reports	✓	✓	✓	✓
Lifetime Replacements	✓	✓	✓	✓
Network	Cellular	Cellular	Cellular	LoRa

Figure 5: Comparing leasing options' additional features for Nordsense, Compology, RecycleSmart and Sensoneo

Comparison of Purchasable Options

Features	NordSense	eCube Labs	WMW	Sensoneo	IoTsens	SmartBin
Software Included	✓	✓		✓	✓	✓
Data Analytics	✓	✓	✓	✓	✓	✓
Raw Data Accessible	✓	✓				✓
Scalability	✓	✓	✓	✓	✓	✓
Company Install						
On Site Support						
Alerts / Reports	✓	✓		✓	✓	✓
Maximum Time to Replacement	10 years	10 years	10 years	10 years	10 years	10 years
Network	Cellular	Cellular	LoRa	LoRa	Cellular / LoRa	Cellular / LoRa / Sigfox

Figure 6: Comparison of purchasable options' additional features of Nordsense, eCube Labs, WMW, Sensoneo, IoTsens, SmartBin

Cost Comparisons Across Services

The following figures summarize the cost of the aforementioned sensors and their respective compatible networks considering subscription (ongoing) costs and fixed costs (one time purchases, or installation).

Dumpsters

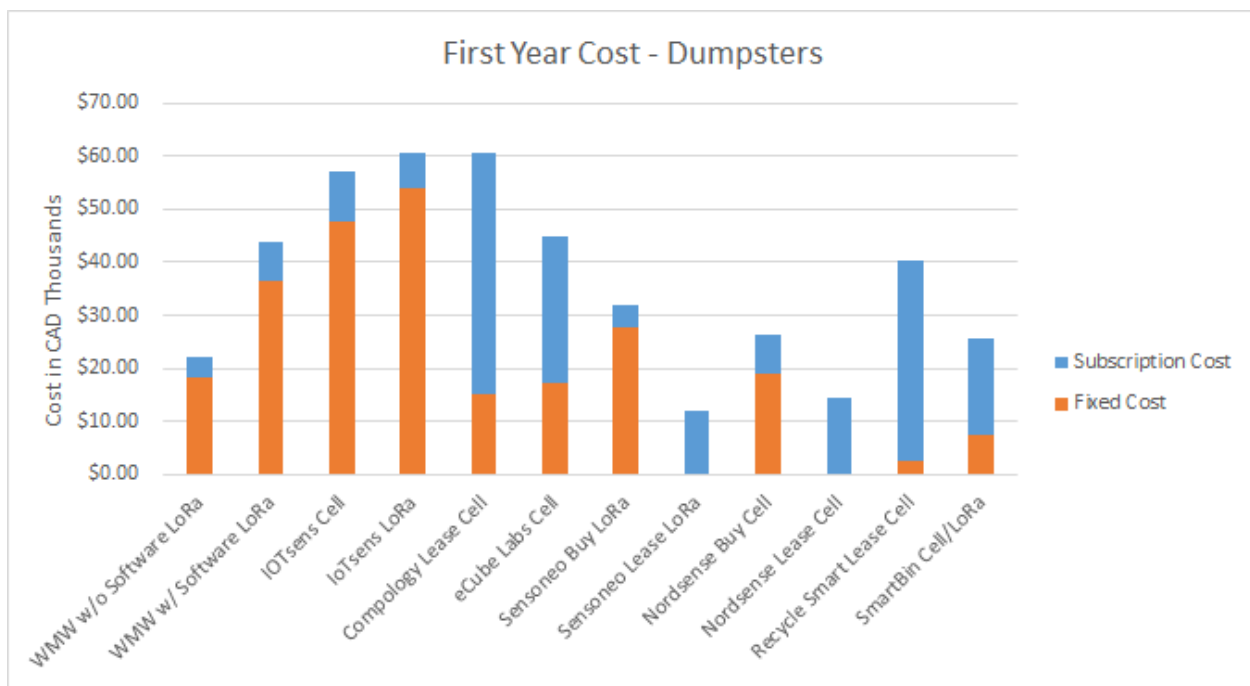


Figure 7: Bar graph of first year total cost of all eight dumpster sensors with their respective compatible networks in thousands of CAD

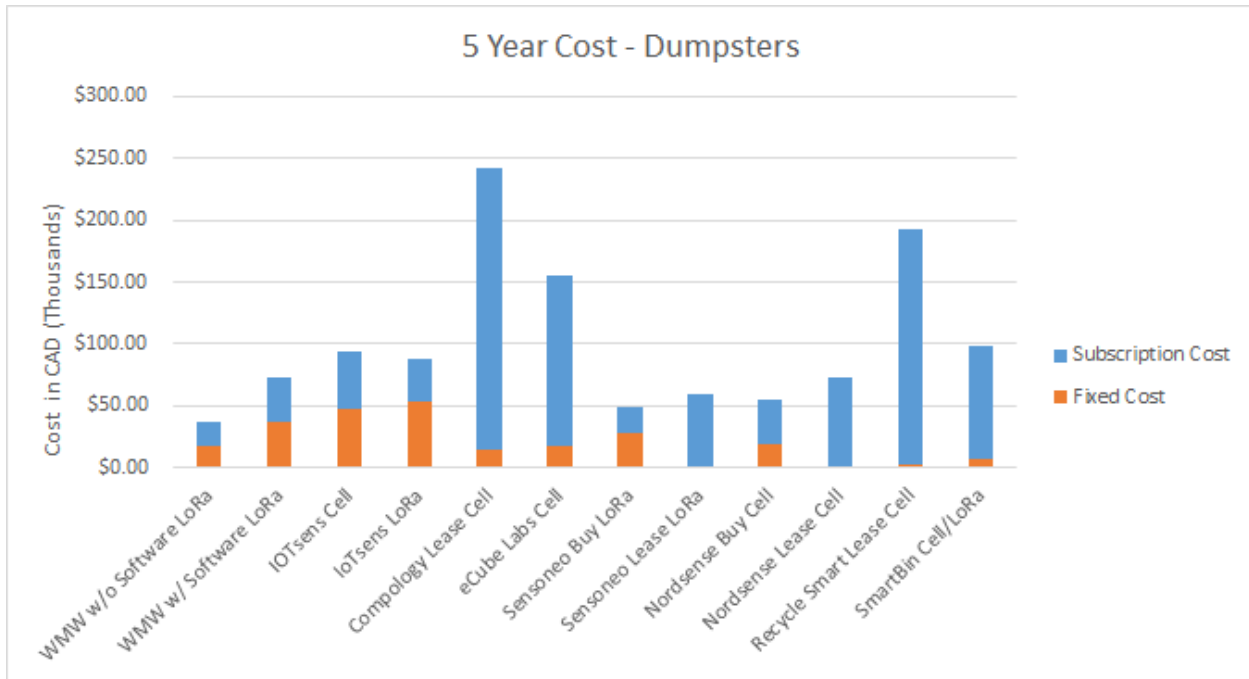


Figure 8: Bar graph of the total cost of the first 5 years of all eight dumpster sensors and their respective compatible networks in thousands of CAD

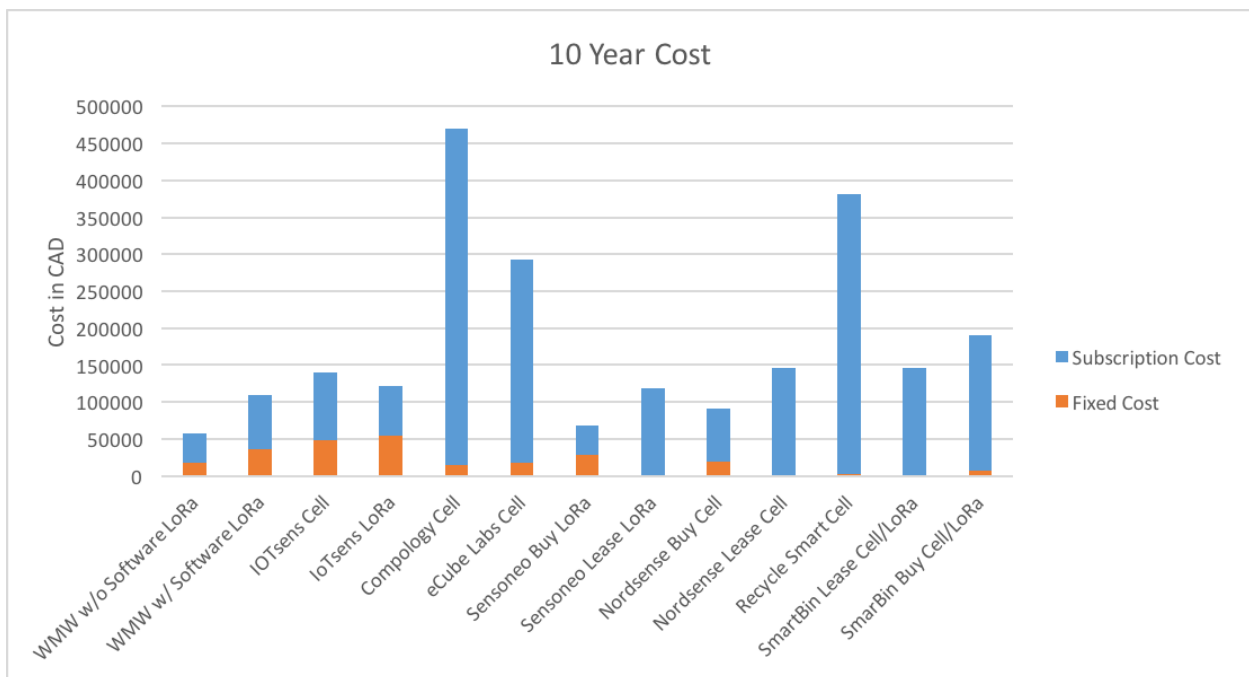


Figure 9: Bar graph of the total cost of the first 10 years of all eight dumpster sensors and their respective compatible networks in thousands of CAD

Figures 7, 8 and 9 consider all 115 bins and their cost over 1, 5 and 10 years respectively. During the initial year (Figure 7), bought solutions such as IoTsens and WMW represent one of the more expensive solutions, whereas leasing options would be more affordable. However, as time progresses (Figure 8 and 9), the subscription costs of lease solutions start to accumulate, and we observe a considerable gap between sensor options that have a high subscription fee, such as Compology and RecycleSmart.

Compactors

The following figures summarize the cost of the aforementioned sensors and their respective compatible networks considering subscription (ongoing) costs and fixed costs (one time purchases, or installation) when used in compactors.

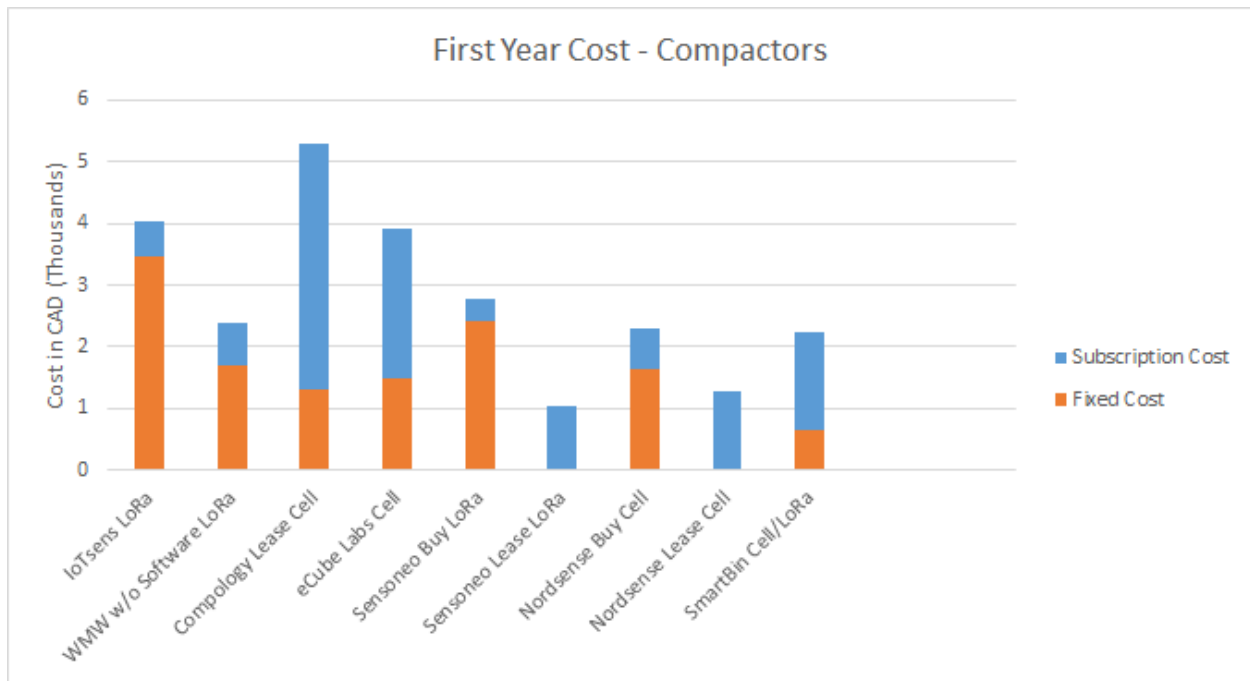


Figure 10: Bar graph of first year total cost of all eight compactors sensors with their respective compatible networks in thousands of CAD

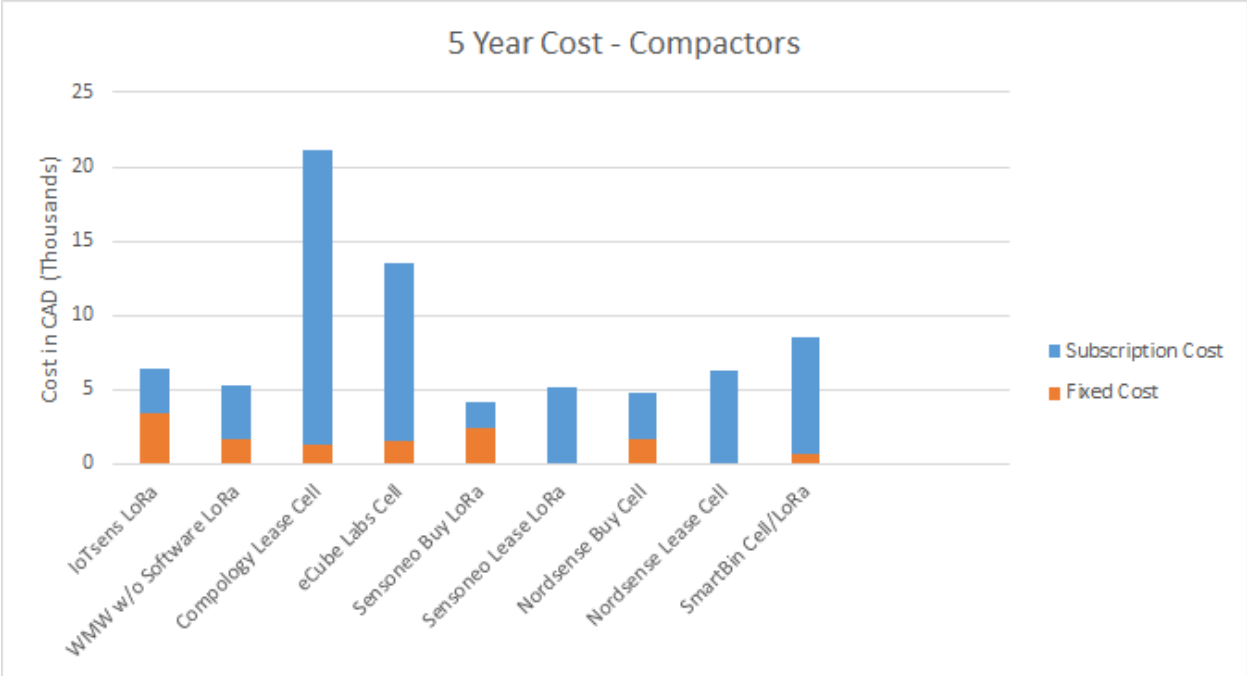


Figure 11: Bar graph of the total cost of the first 5 years of all eight compactor sensors and their respective compatible networks in thousands of CAD

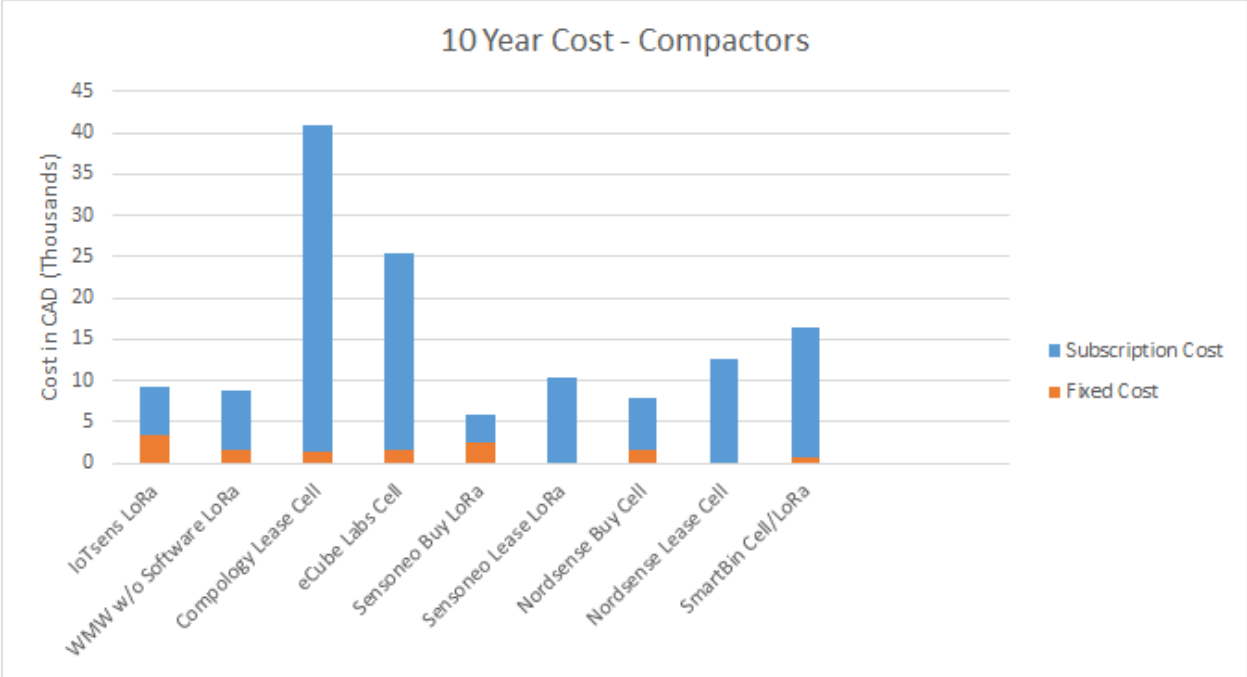


Figure 12: Bar graph of the total cost of the first 10 years of all eight compactor sensors and their respective compatible networks in thousands of CAD

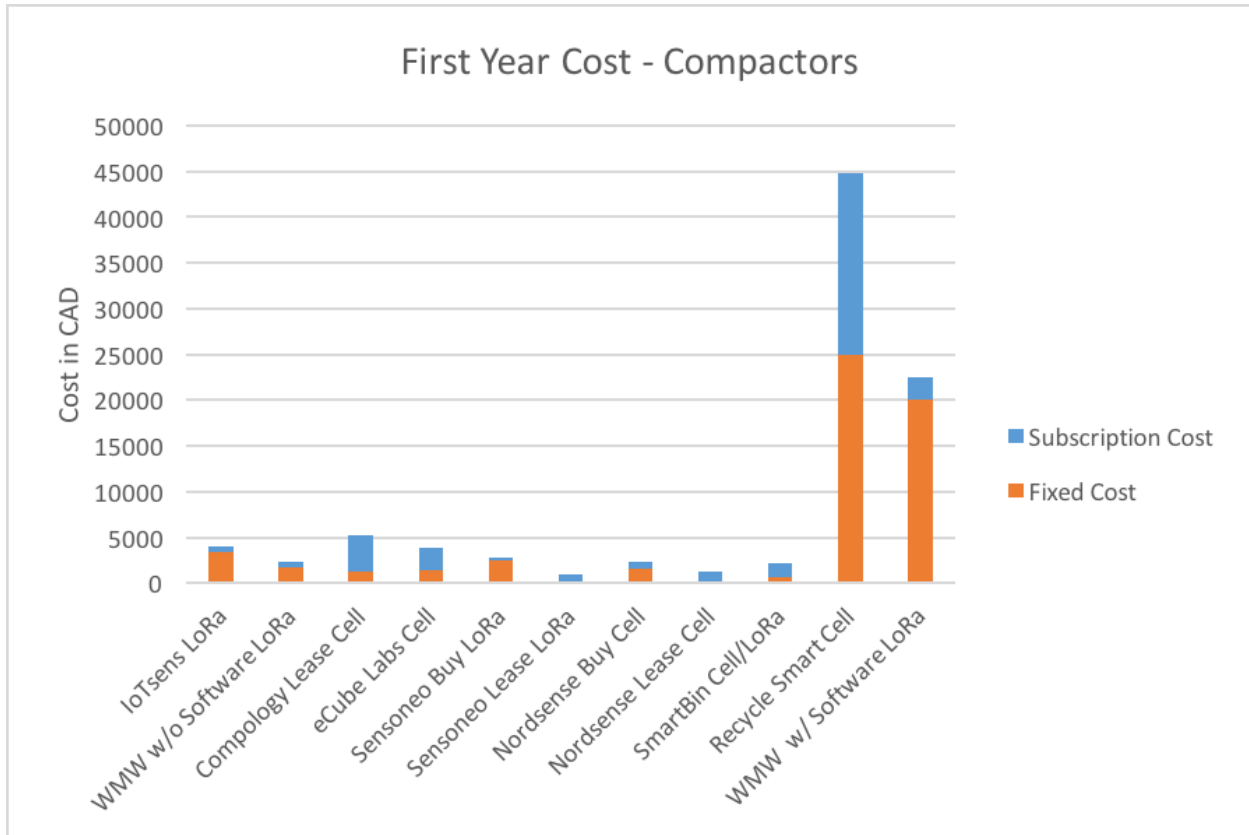


Figure 13: Bar graph of first year total cost of all eight compactors sensors with their respective compatible networks in thousands of CAD

After obtaining quotations from 8 companies, our group constructed three bar graphs that show the total cost of compactors sensors over 1, 5 and 10 years. As observed before with the dumpster sensors, costs during the first year for purchased solutions tend to be higher for compactor sensors. This higher investment, however, is going to be diluted in the long run, when subscription costs tend to be less cost-efficient.

Figure 13 included RecycleSmart’s solutions for compactors, and we see that their costs are significantly higher when compared to other companies’. Therefore we opted for removing RecycleSmart from previous graphs (Figure 10, 11, 12) in order to have better resolution of other bar graphs.

Scoring Services

In order to select the best option to meet UBC Waste Management’s needs, we had to quantitatively compare all the sensors. Therefore a points and weights system was formulated.

In total eight different criteria were considered: fixed costs, ongoing costs, ease of implementation, ease of maintenance, reliability, extra features, functional life, and scalability. Each criteria was given a weight from 0 to 10, 0 being of lesser importance or unimportant and 10 of most importance. We include an excel document with this report, to make it possible to adjust the scores and weights in each criteria to meet SEEDs and UBC needs (i.e. adjust to better reflect UBC’s goals). All other criteria besides fixed and ongoing/monthly costs were scored in a semi arbitrary way, though effort was made to describe each scoring, this too is subjective and UBC may want to adjust the scoring scheme. The following figure illustrates the semi arbitrary scoring scheme we used.

All these criteria will be scored out of 5 but a decimal or fraction score is possible. i.e. 4.5 is allowed					
	1 (give 0 with discretion)	2	3	4	5
Ease of implementation	difficult to install, or implement, requires many infrastructures to be built, and high expertise.	(slightly)simplified implementation still requires a degree of effort and some loops to jump through	acceptable implementation of the system - no need for any infrastructure to be built or loops to jump through (i.e. policymaking) but labor is still necessary.	greatly simplified implementation process. no infrastructure or 'loops' and manual labor in installation is light.	either the company provides installation for free or is included in the listed price, or installation virtually takes no effort.
Ease of maintenance	difficult to maintain - requiring expertise and specialized equipment.	some expertise required or low level equipment needed for maintenance.	easy to maintain - anyone can do with proper instruction.	simplified maintenance	maintenance services given by the company for free or easy to maintain or will never require maintenance
Reliability	not reliable		mostly reliable		very reliable
Additional Features	no additional features	1-2 additional features	2-3 additional features	4-5 additional features	>5 additional features
Functional Life	short term <1 year	1-5 years	5-10 years	long term >10 years	virtually immortal
Scalability	not scalable or hard to scale	scalable but costs become sharp	scaleable without cost changes	easily scalable - not only with the same company	Scalable not only to waste monitoring but also to other IoT monitoring systems
For costs we need to first determine which is least expensive and from that we can do something. Invert fraction of least cost.					

Figure 14: Description of scoring scheme used for non quantitative criteria.

As for fixed and ongoing costs, we determined the score of each solution by finding the solution with the lowest fixed cost and the solution with the lowest ongoing cost (that is non-zero). All other solutions’ scores are calculated by dividing the lowest cost by its cost (zero cost solutions score full points in this case) and multiplying by 10. The following figure shows how each solution fared with, what we consider, to be a viable weight spread across criteria. Here, we placed ongoing costs as the most important criteria and based other weights with reference to the importance of ongoing costs. Reliability scored fairly high here as we felt that it UBC will

greatly value a reliable solution that will not require maintenance or the employment of experts to keep the system running.

Scoring Different Solutions								Total Weights	
Weights (percentage)	0.10416667	0.20833333	0.08333333	0.10416667	0.16666667	0.0625	0.14583333	0.125	1
Weights >> (/10)	5	10	4	5	8	3	7	6	48
Criteria >>	Fixed Cost	Ongoing/ Monthly Costs	Ease of Implementation	Ease of Maintenance	Reliability	Extra Features	Functional Life	Scalability	Total Score (/10)

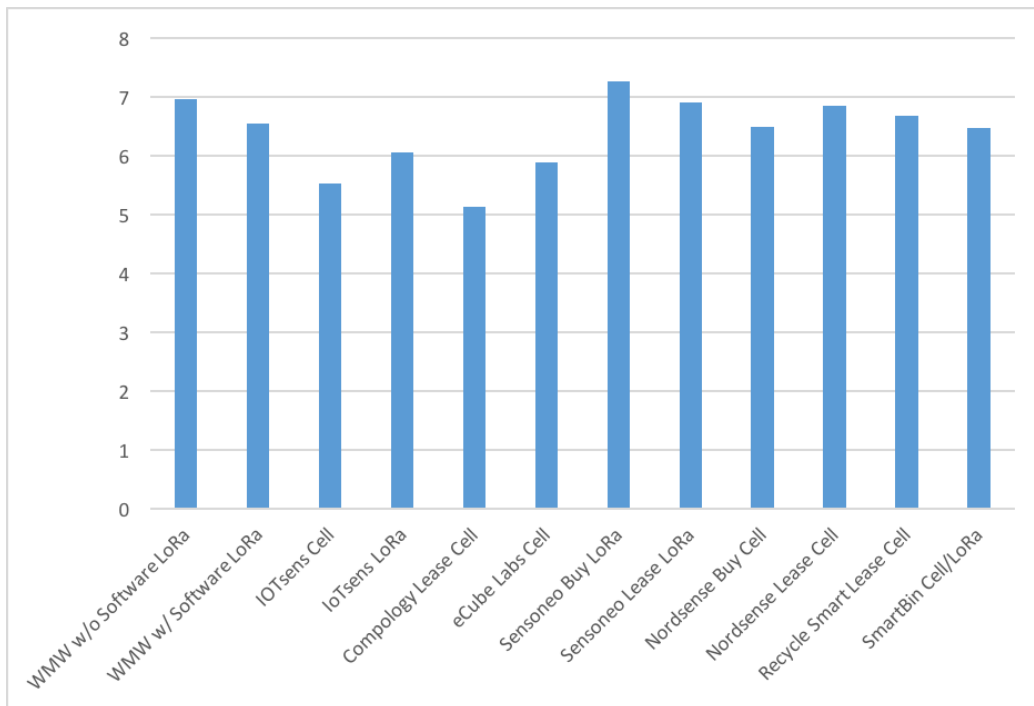


Figure 15: Bar graph of total points of all the sensors and their respective compatible networks when weights were chosen according to what our group considered appropriate

Final Recommendation

After building a first model with semi-arbitrary weights, we considered different scenarios by changing the values of the weights. In Figure 16, the ongoing costs criteria was given an exaggerated weight scoring of 20, meaning that a competitive price would be the most important factor (more so than our initial scoring). We observed WMW without software/LoRa and the

purchased Sensoneo/LoRa sensors scored highest, though other companies remained relatively competitive.

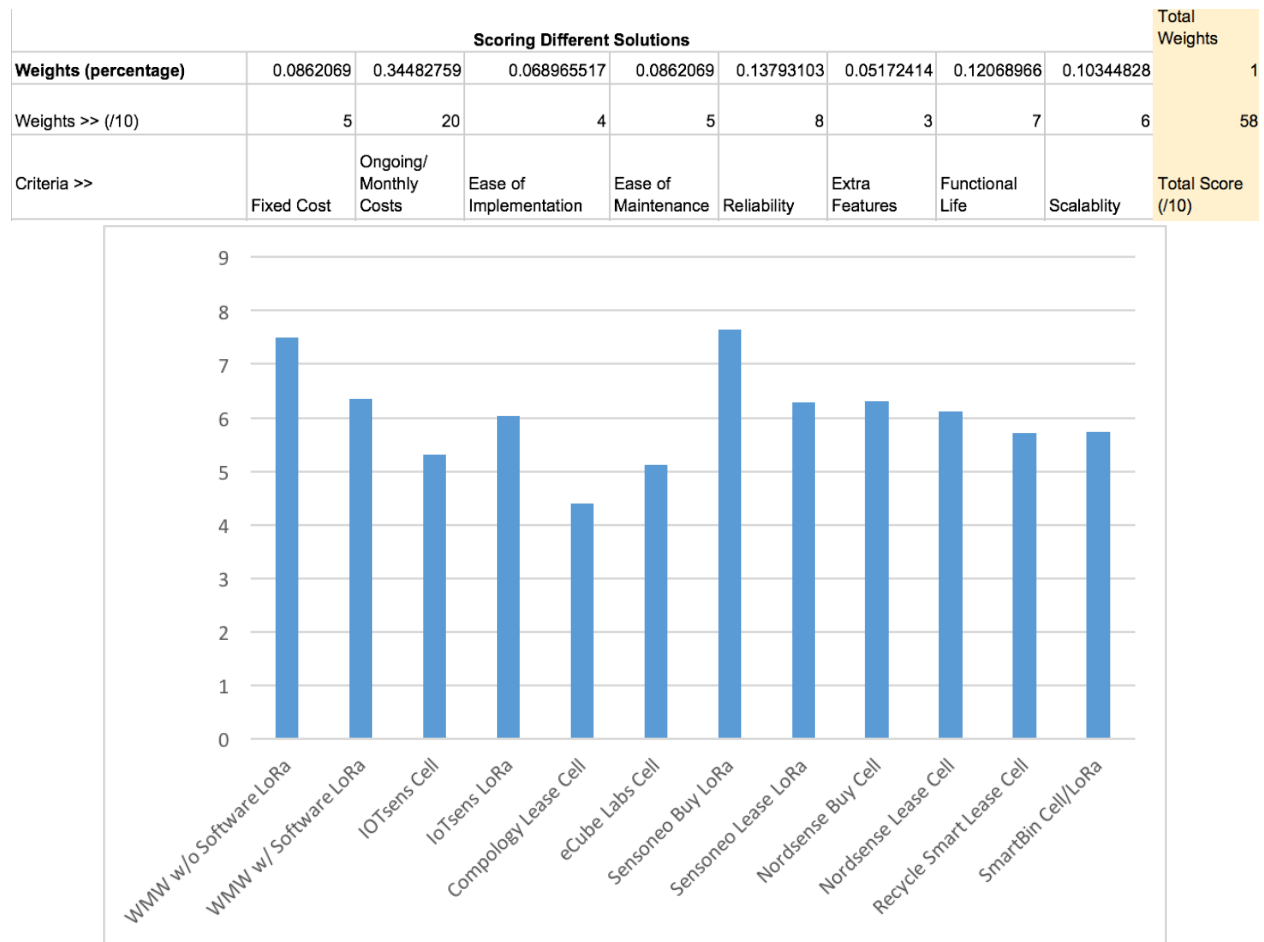


Figure 16: Bar graph of total points of all the sensors and their respective compatible networks when monthly costs' weight was extrapolated to double of the one in Figure 10.

When considering only the costs (both the fixed and ongoing costs) involved with each type of sensor we compare the given alternatives based on which would be the most cost effective option. Figure 17 below shows the scores given to each category in order to allow us to assess the cost driven data. We scored every category apart for the costs as 0, the fixed costs as a 5 and the monthly costs with a score of 10. Our scoring places fixed costs as being less important than monthly costs due to the fact that these payments would only be made once. We see again, that purchased Sensoneo/LoRa as well as WMW without software/LoRa scored highly in terms of costs.

Scoring Different Solutions									Total Weights
Weights (percentage)	0.33333333	0.66666667	0	0	0	0	0	0	1
Weights >> (/10)	5	10	0	0	0	0	0	0	15
Criteria >>	Fixed Cost	Ongoing/ Monthly Costs	Ease of Implementation	Ease of Maintenance	Reliability	Extra Features	Functional Life	Scalability	Total Score (/10)

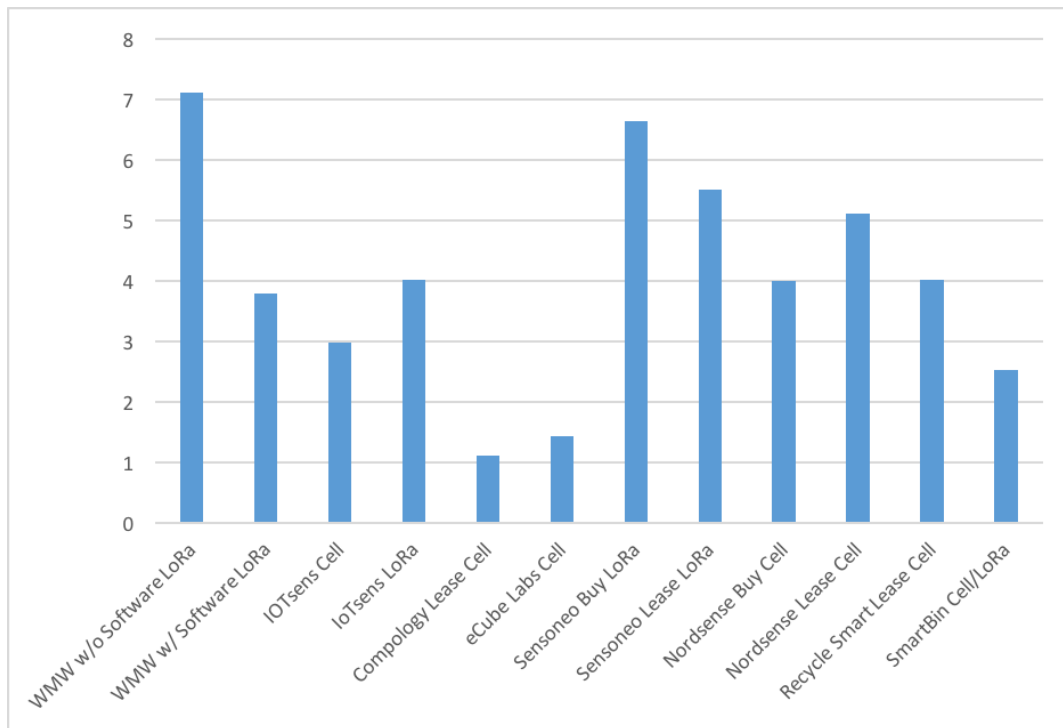


Figure 17: Bar graph of total points of all the sensors and their respective compatible networks when quality features were completely disregarded, but maintaining the cost weights identical to Figure 10.

Next, our team analyzed the qualities and features of each sensor disregarding costs (Figure 18). This allowed us to examine companies based on the quality of their service and systems. We believe that simply having a cost effective system would not be enough and that the system should also meet as many of the needs of UBC’s waste management as possible. We decided that the ease of implementation should score the highest in terms of importance, and that the amount of extra features would be the least important aspect. Here we see that Recycle Smart scored highest though all other companies remained competitive. This is likely due to the fact that Recycle Smart is a local company, providing full service solutions as well as in person technical support.

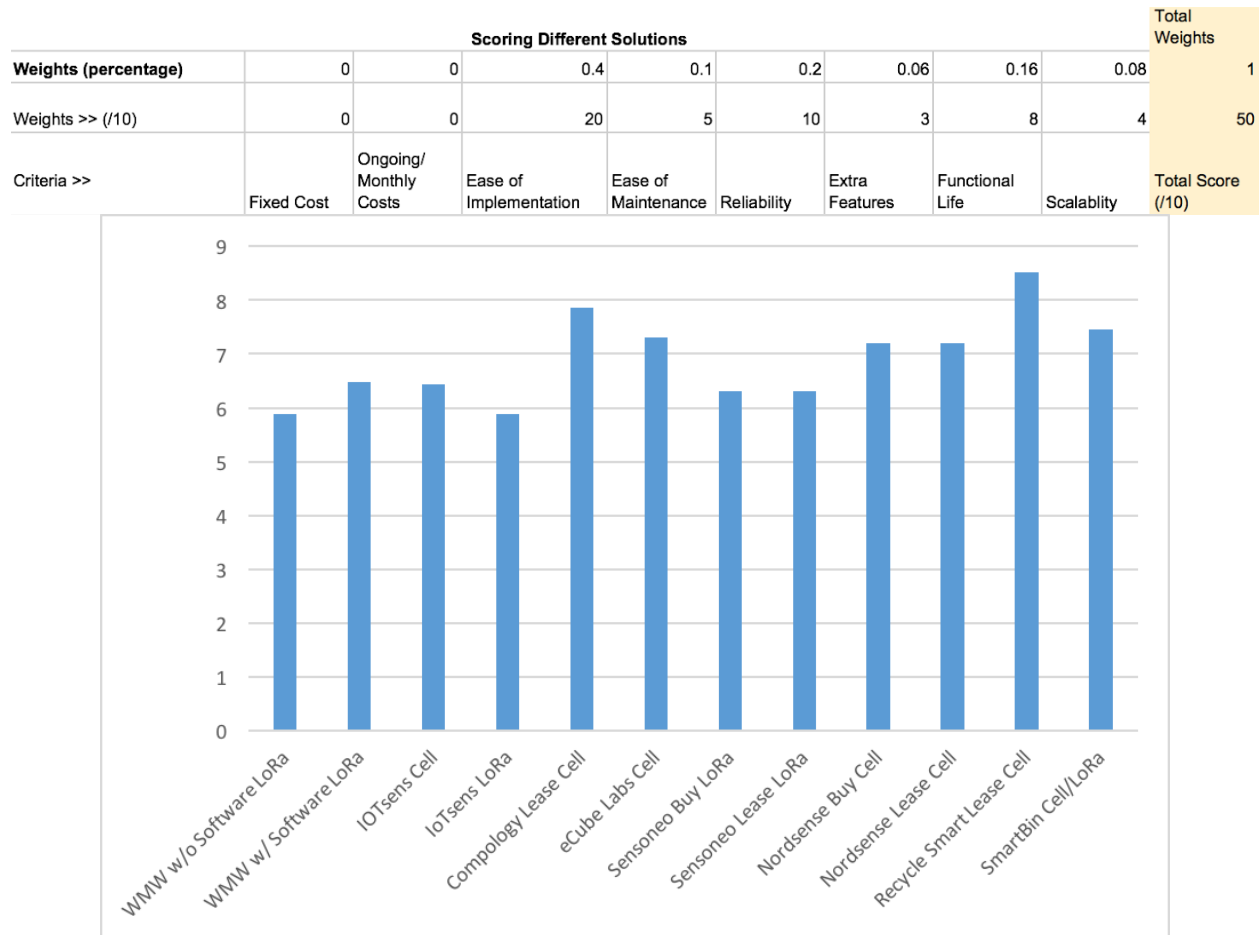


Figure 18: Bar graph of total points of all the sensors and their respective compatible networks when costs were completely disregarded, but maintaining the other weights identical to Figure 10.

The different scenarios simulated above in figures 15, 16 and 17, show that Sensoneo scored highest when given semi-arbitrary weights chosen by our group; second highest when only costs were considered, and had an average value when costs were completely disregarded. The consistently good performance of Sensoneo under different conditions led us to recommend it as the best option for UBC Waste Management (either bought or leased). Moreover, the LoRa network that is compatible with Sensoneo would allow UBC to implement other Internet of Things network solutions on campus such as traffic and energy monitoring. This is because LoRa communicates with wider variety of sensors and supports a higher amount of connections at much lower costs when compared to current cellular network options.

Conclusion

The Student Consulting group extensively researched eight different sensors and three different networks in order to meet UBC Waste Management's needs: monitor waste fill level in dumpsters and compactors around the UBC Camps to better manage waste.

Initially we found more than eight options. However, we were able to rule out some sensors for not being deployed in Canada, or for being disproportionately more expensive than other solutions. Other options of networks were also found, but discarded for not being as common, thus limiting its use with a wide variety of sensors. After narrowing down the scope of our research, we obtained quotes from the eight remaining sensors and their respective three compatible networks: deemed as plausible and diverse options for UBC Waste Management.

After obtaining more information on sensor features as well as pricing, we were able to compare each solution by price, and the its projection in five and ten years. Moreover, a points system enabled us to measure and compare the solutions quantitatively while considering both price and quality. Then, different scenarios were considered: analysing options weighting costs as most important, disregarding costs completely, and only evaluating costs.

In all three scenarios described above, Sensoneo proved to be consistent in its results. Furthermore, Sensoneo's compatibility with the LoRa network will not only be economically efficient, but also open the possibility of installing an Internet of Things at UBC, given the capacity of LoRa to connect to different types of sensors, and still support a large quantity of them.

In view of both the present situation and the future consequences this project would have for UBC Waste Management, the Student Consulting Group's final recommendation for the best sensor/network combination is Sensoneo/LoRa. We believe that it would address the needs of UBC and it would also serve as a base for building up future technologies.