ANALYSIS AND APPLICATION OF THE TARGET SET SELECTION TO THE CARBON OXIDE DATA OF U.P. BAGUIO

by

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A special problem submitted to the
Department of Mathematics and Computer Science
College of Science
The University of the Philippines
Baguio, Baguio City

as partial fulfillment of the
requirements for the degree of
Bachelor of Science in Computer Science

May 2019

This is to certify that this Special Problem entitled **"Analysis and Application of the Target Set Selection to the Carbon Oxide Data of U.P. Baguio"**, prepared and submitted by **Cary Quibada** to fulfill part of the requirements for the degree of **Bachelor of Science in Computer Science**, was successfully defended and approved on May 2019.

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The Department of Mathematics and Computer Science endorses the acceptance of this Special Problem as partial fulfillment of the requirements for the degree of Bachelor of Science in Computer Science .

JERICO B. BACANI, DR.RER.NAT.
Chair
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Computer Science

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Acknowledgments

I would like to express my deepest gratitude to the people who helped me throughout my fourteen years of education. First, I would like to thank: Pa, Ma, Ate, Titos and, Titas who have guided me to the path I am taking today. Without your advice, encouragement, and support, I would not have gone this far. I hope to repay you guys in the near future. Second, I would like to thank Dr. Joel Addawe, for always being open to our queries and for the long discussions that helped us with this thesis. Third, I give my thanks to Patricio Casurao who conducted this study with me.

Abstract

Analysis and Application of the Target Set Selection to the Carbon Oxide Data of U.P. Baguio

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In the University of the Philippines Baguio, the Carbon Monoxide (CO) and Carbon Dioxide (CO_2) parts per million (PPM) were monitored and collected. Fifteen locations were considered, all encompassing the campus. These fifteen locations were made into a geo-spatial graph with the fifteen locations being considered as nodes and the paths leading to them as edges. The data collection was conducted for three days and each day had three time slots for the data collection. Two rush peak time slots were considered, morning peak time slot(7:30-9:00 AM),afternoon peak time slot(4:30-6:00 PM), and an off peak time slot(1:30-3:00 PM) was also considered . UP Baguio's Car-less Wednesday was taken into account to see the effects the program had on the general air quality of the campus. To compare the emission levels, weekday (Thursday) and weekend (Saturday) were also considered. Twenty-four hour Carbon Oxide data was also monitored for four days to see the general trend through time of the Carbon Oxide in the campus. Two information dissemination in a social network graph algorithms were then applied to the network to find out which locations are the ideal spots for placing air filters. This is to find out the ideal areas where we can clean the air quality of the campus, so that all other areas in the campus are affected by the change of the air quality in the areas selected. The areas selected by the two algorithms can also be considered as the locations most dangerous to the respiratory health of the students and staff alike. High concentrations of CO and CO_2 were seen on weekdays, peak time slots, and locations near sources of CO and CO_2 such roads.

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Chapter 1

Introduction

1.1 Background of the Study

University of the Philippines Baguio is a university campus established in 1961, with a population of the nearly 3,000 students based on UP Statistics 2013[35]. In the study by Costales et al.[9], this campus in Baguio has the 2nd highest particulate matter 10(PM_{10}) having 144 micrograms per cubic meter(behind Baguio City Police Office's 193 micrograms per cubic meter). The city government of Baguio has initiated numerous environmental projects in efforts to address Baguio's air quality problem. This includes the Road Inspection, Testing, and Monitoring Team (RITMT) operations of monitoring and the penalizing of vehicles that highly contribute on air pollution, as published by an article on the City of Baguio's website[5]. An RITMT emission testing station is located in front of UP Baguio's main gate to penalize vehicles with high carbon emission.

UP Drive is one of the entry points to the Baguio Central Business District. It circumscribes the UP Baguio Campus. Many types of vehicles including Jeepneys, Taxis, private vehicles, buses, and even trucks pass through this road. These gasoline and diesel-fed vehicles produce dangerous pollutants such as Carbon Monoxide (CO) and Carbon Dioxide (CO_2). According to an EMB report[13], Carbon Monoxide is a gas that decreases the capacity of the human blood to carry oxygen. It is mainly emitted from vehicle exhaust. While Carbon Dioxide, as stated by De Nevers[10], acts as a 'global temperature regulator' for its known green house effect. Unnatural sources of CO_2 includes deforestation and the burning of fossil fuels for energy.

Aside from UP Drive, UP Baguio Campus is also circumscribed by the Governor Pack Road, where the Bus terminals are located and Harrison Road that leads to the Baguio Plaza, the Jeepney's Central Terminal. Because of this, UP Baguio's Campus is right at the center of numerous smoke producing areas in Baguio City. This puts it's students at risk of potential health threats from the quality of air they breathe.

In the collection of the data for this study, an Arduino Uno microcontroller will be used along with multiple sensors that are used for collection of data concerning gases, temperature and humidity. To save the data, a Bluetooth module was used on a later version of the module. This was used to send the data to a smartphone and saved by an Android application made using MIT's App Inventor 2.

1.2 Statement of the Problem

Air in Baguio City has been deemed the dirtiest in the country in 2014[17] based on the database made by the WHO[37]. This is a major health risk for young college students who might later on, experience problems with their respiratory system from their four or more years stay in Baguio. As claimed by an EMB report[13] and by the study of Selmi et al.[32], trees can act as air purification filters which can combat the high Carbon Oxide concentrations that act as pollutants in the air. Placement of forest covers can be costly and inefficient when not studied due to them taking up space meant for facilities and classrooms to be used by students and the staff.

According to Robinson, Webber, and Eifrem [30], a geo-spatial graph is a type of graph that represents data in a geological space. This type of graph has a similar structure as a simple graph which has vertex and edge set. The vertex set is the set of specific locations in a geological space and the edge set are the connection such as roads in which the locations are defined to be linked together. As early the time of Euler, he already used the concept of geospatial graph to solve the Seven Bridges of Königsberg Problem.

A geo-spatial graph will help us represent the UP Baguio environment in terms of the concentration of gases such as Carbon Monoxide and Carbon Dioxide. Specific collection locations around UP Baguio act as nodes in the graph. Through the proposed target set selection algorithms, with the thresholds as ranges of gas PPM concentrations, we can determine which areas are said to be 'influencers' in terms of the gas concentrations. The proposed target set selection algorithm was derived from a paper by Cordasco et al.[8].

1.3 Objective of the Study

1.3.1 General Objective of the Study

This study aims to find the least set of locations in the geo-spatial graph that if air filters such as trees are placed, the air quality level in the whole campus would be acceptable. In order to find these places, we need to find a way to apply the Target Set Selection Algorithms to geo-spatial graphs.

1.3.2 Specific Objective of the Study

The study aims to apply the Target Set Selection Algorithm (TSSA), a information dissemination algorithm, to UP Baguio to identify which areas are to be considered as the Target Set or the area where air filters are to be placed. In doing so, we will need to collect Carbon Oxide data at certain locations. In the study, we will define the sections for the placement of filters such as trees to reduce Carbon Oxide levels and have acceptable air quality level in the campus. To analyze and understand the trends of Carbon Oxides within the campus, we need:

1. To collect CO/CO_2 readings in Wednesday, Thursday and Saturday.
2. To collect data on different time slots for all the days at 7:30-9:00 AM, 1:30-3:00 PM and 4:30-6:00 PM.
3. To collect readings at every five minutes time interval for every location.
4. To collect twenty-four hour readings for specific days.

1.4 Significance of the Study

If the identified target set areas can be addressed such that there will be an air filter placed on it, thus cleaning the air. This will lead to positive effects on the respiratory health conditions of students in the campus.

We make a graph as representation of the different locations in the UP Baguio Campus. When identifying the least target set of the graph, we obtain the least amount of nodes, thus the cheapest set of nodes that will help in clearing the pollutants in the air. This can lead to a fairly cheap but effective plan that can eventually decrease the rank of UP Baguio in the list of areas having high concentrations of pollutants from the study of Costales et al.[9]. The data obtained in this study can be used on future air quality studies by other researchers.

1.5 Scope and Limitation

This study is limited to selected parts of UP Baguio, where majority of students gather and walk through. Three days were selected for data collection in the end of March 2019 and the month of April 2019. For each of the days, three time intervals of one and a half hours were allotted for the data collection. Fifteen campus locations were considered.

The limitation of the study is the simplified assumptions considered in the proposed target set selection algorithms. The study does not consider wind speed and direction, gas diffusion rates, slopes of the pathways, and other physical characteristics. Due to time and financial limitations, only two sets of Arduino sensor modules were used.

Chapter 2

Review of Related Literature

2.1 Target Set Selection

The Target Set Selection problem mainly involves Internet social networks. It is primarily advised to be used by advertisers in identifying the group with the least amount of members in a social network of whom to "influence" in order to disseminate information to the whole network. Cordasco et.al[8] have developed the TSS algorithm which is proven to be effective in finding a small Target Set in a network. Modifications are to be done to the algorithm to fit the model we will use in representing air quality as nodes in a graph.

In applying Target Set Selection, we define a simple graph $G = \{V, E\}$ where $V = \{v_1, v_2, ..., v_n\}$ and $E = \{\{v_1, v_2\}, \{v_2, v_3\}, ..., \{v_{n-1}, v_n\}\}$. Also, each $v \in V$ has a threshold t where $1 \leq t \leq deg(v)$. In the model we have nodes that can be active and inactive, node can be active when they have been influenced, meaning that their threshold t reach zero or if they are picked to be in part of the target set. Otherwise, the node is inactive. If the node is considered as active, the neighbors of this node would reduce their threshold by one. The activation process would end if all of the nodes have their thresholds as zero.

Numerous algorithms have been developed in attempt to solve this problem. The TIP-Decomp[33] algorithm, VirAds[12] algorithm, Greedy algorithm[8] and TSS algorithm[8] are some of the known algorithms that give optimal solutions to the Target Set Selection Problem. In our study, the **TSS** and **Greedy TSS** algorithms appear to be the algorithm that can be modified to suit the model that we will be applying for our collected data. So we will utilize both to find the solution to the Target Set Selection Problem. Modifications will be made to these algorithm as we will be using different parameters compared to the existing model for social networks.

Algorithm 1 TSS Algorithm

Require: $G = (V, E)$, Thresholds $t(v)$ for $v \in V$

Ensure: Target Set S

```
S = ∅
U = V
for all v ∈ v do
    δ(v) = d(v)
    k(v) = t(v)
    N(v) = Γ(v)
end for
while U ≠ ∅ do
    if there exists v ∈ U s.t k(v) = 0 then
        for all u ∈ Nv do
            k(u) = max(k(u) − 1, 0)
        end for
    else
        if there exists v ∈ U s.t δ(v) ≤ k(v) then
            S = S ∪ {v}
            for all u ∈ N(v) do
                k(u) = k(u) − 1
            end for
        else
            v = argmax_{u∈U}{ k(u) / (δ(u)(δ(u)+1)) }
        end if
    end if
    for all u ∈ N(v) do
        δ(u) = δ(u) − 1
        N(u) = N(u) − v
    end for
    U = U − v
end while
```

Variables Used in the Algorithm:

- S: The resulting target set
- $d(v)$: Degree of vertex v
- $t(v)$: Threshold of vertex v
- $\Gamma(v)$: Neighbor set of vertex v

This algorithm considers three cases in identifying the target set in the network. The first case is if there exists a vertex v in the set where the threshold is zero. If this case passes, we reduce thresholds of its neighbors by one. The second case is when there exists a vertex v in the set where its degree is less than the its threshold. For this case to pass, the node must have enough neighbors that have been considered in the third case of this algorithm. If it does pass, we include that vertex into the resulting Target Set. The third case for this algorithm is the selection of the current v in the set that will be suitable for removal, the nodes typically considered in this case are the ones with low degrees or high thresholds or both at the same time. The discussion on the alterations to be done to this algorithm will be done in the methodology.

TSS Step by step example

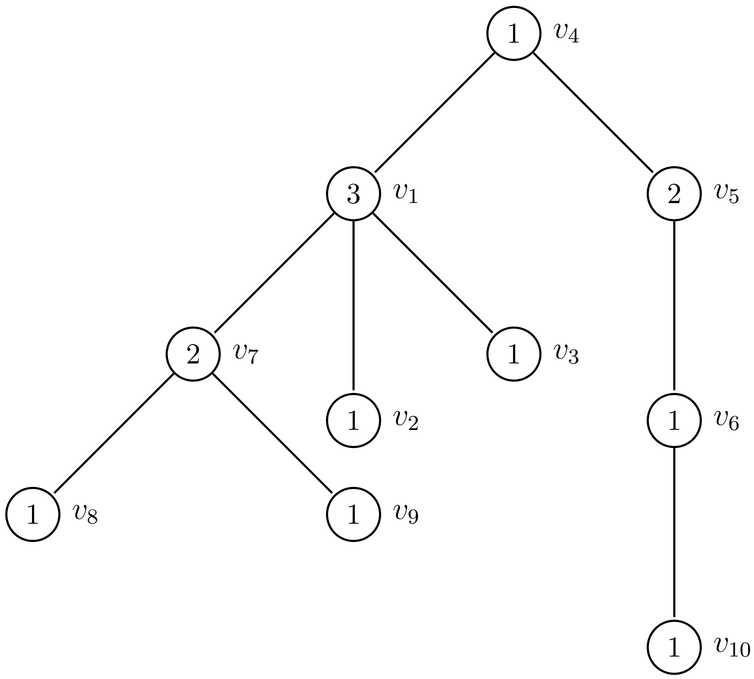


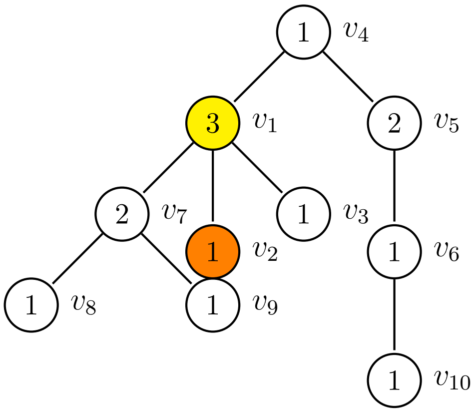
Figure 2.1: A tree with 10 vertices where the number inside the circle is the vertex threshold $(t(v))$.

Vertex v_i	Degree d_i^{in}	Threshold t_i	$TSSmax(v)$
v_1	4	3	0.15
v_2	1	1	0.5
v_3	1	1	0.5
v_4	2	1	0.16667
v_5	2	2	0.3333
v_6	2	1	0.16667
v_7	3	2	0.1667
v_8	1	1	0.5
v_9	1	1	0.5
v_{10}	1	1	0.5

Summary of the run time

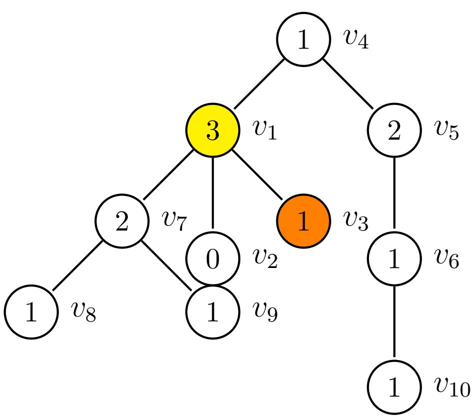
$$\begin{array}{lcccccccccc} Iteration & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 \\ vertex & v_2 & v_3 & v_1 & v_4 & v_5 & v_6 & v_{10} & v_8 & v_7 & v_9 \\ Case & 3 & 3 & 2 & 1 & 3 & 3 & 2 & 3 & 3 & 2 \end{array} \tag{2.1}$$

Iteration 1, Case 3, $v = 2$



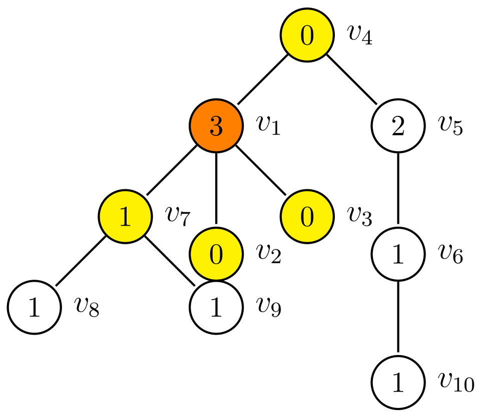
Vertex v_i	Degree d_i^{in}	Threshold t_i	$TSSmax(v)$
v_1	4	3	0.15
v_2	1	1	0.5
v_3	1	1	0.5
v_4	2	1	0.16667
v_5	2	2	0.3333
v_6	2	1	0.16667
v_7	3	2	0.1667
v_8	1	1	0.5
v_9	1	1	0.5
v_{10}	1	1	0.5

Iteration 2, Case 3, $v = 3$



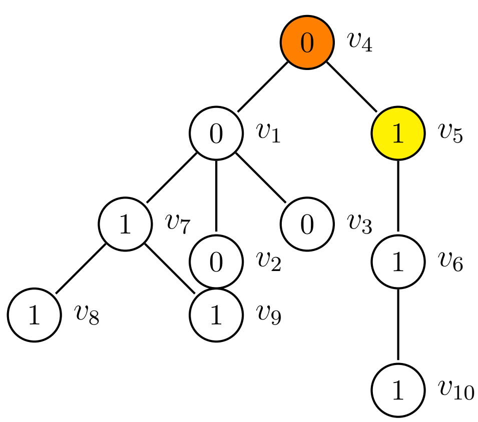
Vertex v_i	Degree d_i^{in}	Threshold t_i	$TSSmax(v)$
v_1	3	3	0.25
v_2	1	0	0
v_3	1	1	0.5
v_4	2	1	0.16667
v_5	2	2	0.3333
v_6	2	1	0.16667
v_7	3	2	0.1667
v_8	1	1	0.5
v_9	1	1	0.5
v_{10}	1	1	0.5

Iteration 3, Case 2, $v = 1$



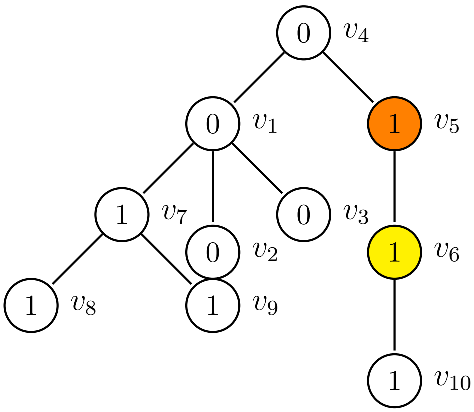
Vertex v_i	Degree d_i^{in}	Threshold t_i	$TSSmax(v)$
v_1	2	3	0.5
v_2	1	0	0
v_3	1	0	0
v_4	2	0	0.16667
v_5	2	2	0.3333
v_6	2	1	0.16667
v_7	3	1	0.1667
v_8	1	1	0.5
v_9	1	1	0.5
v_{10}	1	1	0.5

Iteration 4, Case 1, $v = 4$



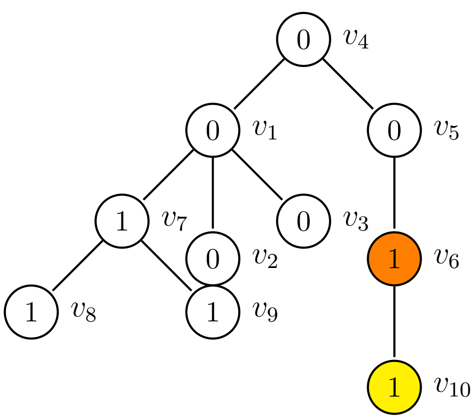
Vertex v_i	Degree d_i^{in}	Threshold t_i	$TSSmax(v)$
v_1	2	0	0
v_2	0	0	0
v_3	0	0	0
v_4	1	0	0
v_5	2	1	0.3333
v_6	2	1	0.16667
v_7	2	1	0.1667
v_8	1	1	0.5
v_9	1	1	0.5
v_{10}	1	1	0.5

Iteration 5, Case 3, $v = 5$



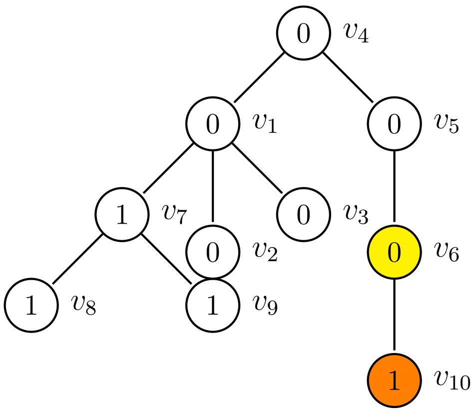
Vertex v_i	Degree d_i^{in}	Threshold t_i	$TSSmax(v)$
v_1	1	0	0
v_2	0	0	0
v_3	0	0	0
v_4	1	0	0
v_5	1	1	0.5
v_6	2	1	0.16667
v_7	2	1	0.1667
v_8	1	1	0.5
v_9	1	1	0.5
v_{10}	1	1	0.5

Iteration 6, Case 3, $v = 6$



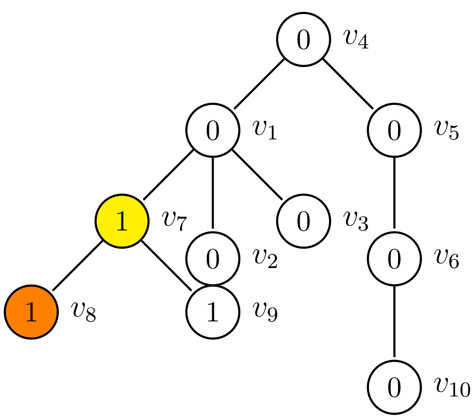
Vertex v_i	Degree d_i^{in}	Threshold t_i	$TSSmax(v)$
v_1	1	0	0
v_2	0	0	0
v_3	0	0	0
v_4	0	0	0
v_5	1	0	0
v_6	1	1	0.5
v_7	2	1	0.1667
v_8	1	1	0.5
v_9	1	1	0.5
v_{10}	1	1	0.5

Iteration 7, Case 2, $v = 10$



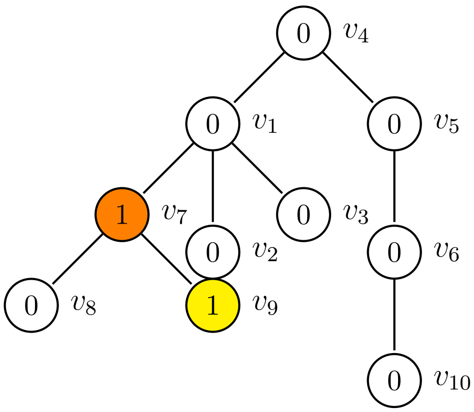
Vertex v_i	Degree d_i^{in}	Threshold t_i	$TSSmax(v)$
v_1	1	0	0
v_2	0	0	0
v_3	0	0	0
v_4	0	0	0
v_5	0	0	0
v_6	1	0	0
v_7	2	1	0.1667
v_8	1	1	0.5
v_9	1	1	0.5
v_{10}	0	1	0.5

Iteration 8, Case 3, $v = 8$



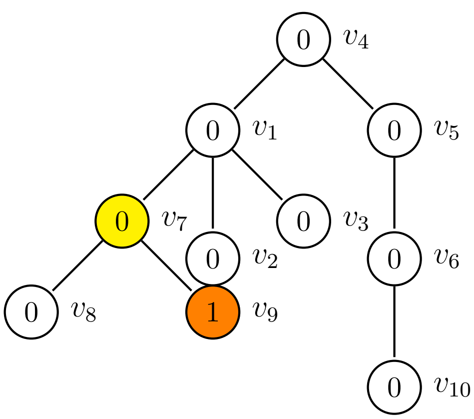
Vertex v_i	Degree d_i^{in}	Threshold t_i	$TSSmax(v)$
v_1	1	0	0
v_2	0	0	0
v_3	0	0	0
v_4	0	0	0
v_5	0	0	0
v_6	0	0	0
v_7	2	1	0.1667
v_8	1	1	0.5
v_9	1	1	0.5
v_{10}	0	0	0

Iteration 9, Case 3, $v = 7$



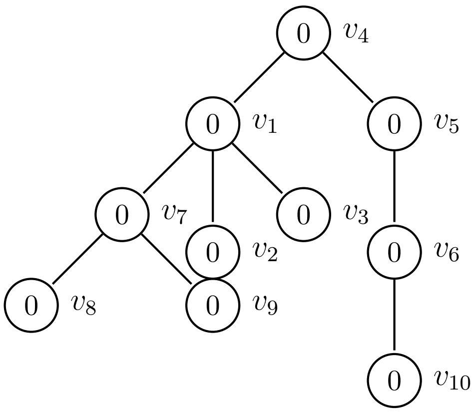
Vertex v_i	Degree d_i^{in}	Threshold t_i	$TSSmax(v)$
v_1	1	0	0
v_2	0	0	0
v_3	0	0	0
v_4	0	0	0
v_5	0	0	0
v_6	0	0	0
v_7	1	1	0.5
v_8	1	0	0
v_9	1	1	0.5
v_{10}	0	0	0

Iteration 10, Case 2, $v = 9$



Vertex v_i	Degree d_i^{in}	Threshold t_i	$TSSmax(v)$
v_1	0	0	0
v_2	0	0	0
v_3	0	0	0
v_4	0	0	0
v_5	0	0	0
v_6	0	0	0
v_7	1	0	0
v_8	0	0	0
v_9	0	1	0.5
v_{10}	0	0	0

Finally,



Vertex v_i	Degree d_i^{in}	Threshold t_i	$TSSmax(v)$
v_1	0	0	0
v_2	0	0	0
v_3	0	0	0
v_4	0	0	0
v_5	0	0	0
v_6	0	0	0
v_7	0	0	0
v_8	0	0	0
v_9	0	0	0
v_{10}	0	0	0

Thus, the target set is $S = \{v_1, v_{10}, v_9\}$

2.2 Greedy Algorithm

Algorithm 2 Greedy Algorithm

Require: $G = (V, E)$, Thresholds $t(v)$ for $v \in V$

Ensure: Target Set S

$S = \varnothing$
$U = V$
for all $v \in v$ **do**
    $\delta(v) = d(v)$
    $k(v) = t(v)$
    $N(v) = \Gamma(v)$
end for
while $U \neq \varnothing$ **do**
    $v = argmax_{u \in U}\{\delta(u)\}$
    if $k(v) > 0$ **then**
        $v = argmax_{u \in U}\{k(u)\}$
        $S = S \cup \{v\}$
    end if
    for all $u \in N(v)$ **do**
        $\delta(u) = \delta(u) - 1$
        $N(u) = N(u) - v$
    end for
    $U = U - v$
end while

The Greedy version of the TSS algorithm, as in its name, picks the most likely vertex to be added to the target set. The algorithm finds the vertex with the highest threshold but includes the node highest degree instead. This ensures that if the thresholds of the nodes are the same but the degrees differ, we still want to pick the most likely node to be in the target set.

Greedy Step by step example

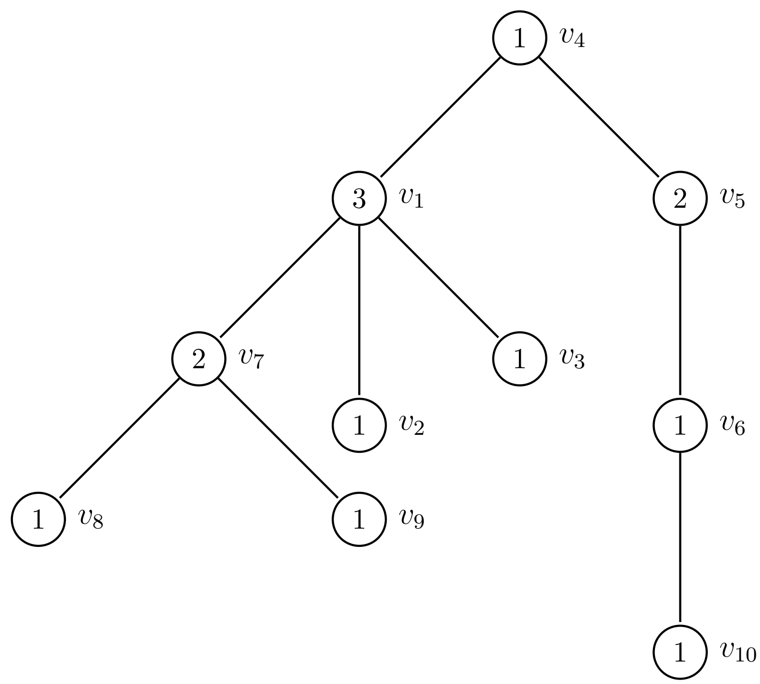
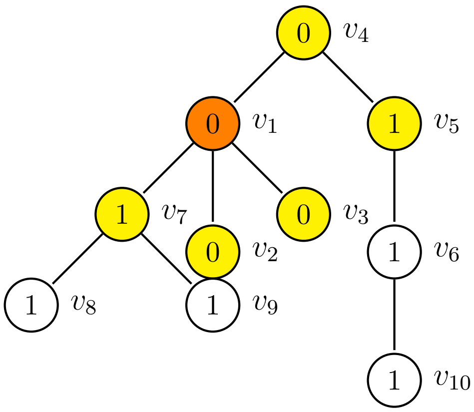


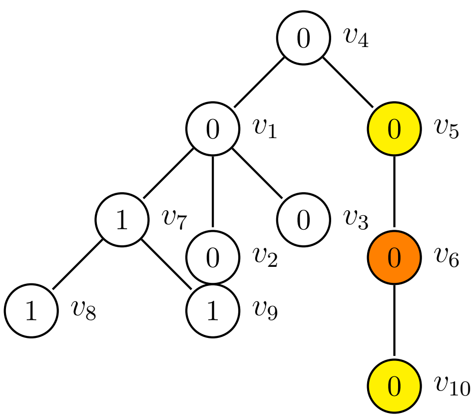
Figure 2.2: A tree with 10 vertices where the number inside the circle is the vertex threshold $(t(v))$.

Vertex v_i	Degree d_i^{in}	Threshold t_i
v_1	4	3
v_2	1	1
v_3	1	1
v_4	2	1
v_5	2	2
v_6	2	1
v_7	3	2
v_8	1	1
v_9	1	1
v_{10}	1	1



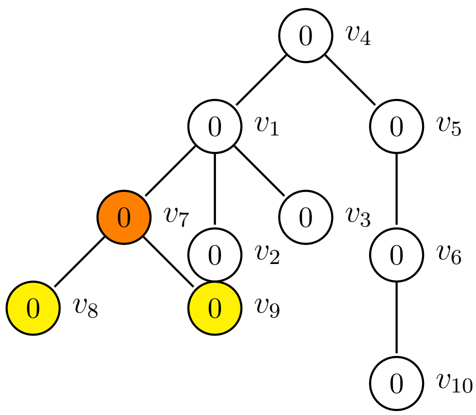
Iteration 1 (v_1)

Vertex v_i	Degree d_i^{in}	Threshold t_i
v_1	0	0
v_2	0	0
v_3	0	0
v_4	0	0
v_5	1	1
v_6	2	1
v_7	2	1
v_8	1	1
v_9	1	1
v_{10}	1	1



Iteration 2 (v_6)

Vertex v_i	Degree d_i^{in}	Threshold t_i
v_1	0	0
v_2	0	0
v_3	0	0
v_4	0	0
v_5	0	0
v_6	0	0
v_7	1	1
v_8	1	1
v_9	1	1
v_{10}	0	0



Iteration		**3**	(v_7)
Vertex v_i	Degree d_i^{in}	Threshold t_i	
v_1	0	0	
v_2	0	0	
v_3	0	0	
v_4	0	0	
v_5	0	0	
v_6	0	0	
v_7	0	0	
v_8	0	0	
v_9	0	0	
v_{10}	0	0	

We can stop here since all of the degrees of the vertices in the graph are 0. We get $S = \{v_1, v_6, v_7\}$.

2.3 Air Quality

2.3.1 Carbon Monoxide

Carbon Monoxide(CO) is a colorless and odorless gas that can be lethal when inhaled in high amounts as defined by National Academy Press[24]. This gas is produced by the incomplete combustion of carbon-containing fuels, i.e. gasoline, coal, etc. In the US, according to NAP[24], the largest contributor to CO are vehicle emissions. Still in NAP[24], Carbon Monoxide is also known to affect the mental state of a person that inhales a large amount of this gas. This condition is called Carbon Monoxide Poisoning. This serious issue often happens in indoor living spaces that have leaks in gas lines. Since this the gas is odorless and colorless, a sensor is needed to detect high concentrations of this gas.

In terms of pollution, this gas would and should not be present in an ideal world but with the rise of machines that has carbon emissions, this gas remains present in our environment. Poor ventilation in areas near vehicles are prone to having high concentrations of Carbon Monoxide. CO is usually low outdoors, but it is not impossible for it to reach the threshold of safe to dangerous. As said by Environmental Protection Agency(EPA)[14], the dangers of having high concentrations of Carbon Monoxide outdoors is primarily for people with heart disease. Carbon Monoxide hinders the flow of oxygenated blood to the heart.

2.3.2 Carbon Dioxide

As defined by Roger[31], Carbon Dioxide(CO_2) is an essential gas that gives life to plants. CO_2 has many natural sources. It can come from respiration and decomposition. It can also come from emissions produced by the burning of coal, fossil fuels and forests. These human activities have contributed in thinning out the ozone layer which is just one of the many harmful effects of having large amounts of CO_2 in the atmosphere. These emissions can also lead to climate change, increases respiratory health risks, endangerment of many species of animals, acid rain, etc. As claimed by ProOxygen [28], the global parts per million (PPM) level of Carbon Dioxide has been worryingly increasing over the past decades. Not only does the value increase, but also its growth rate. Which was 1.06 ppm per year in 1965 to 2.11 ppm per year in 2014. This trend is to blame for Global Warming that is a result of the thinning of the ozone layer attributed to carbon emissions.

2.4 Current Studies of Air Quality in Baguio

Only two known studies have been made about air quality in Baguio. Both of these studies have used the PM_{10} data of Baguio City Central Business District.

For the first study by Cassidy et al.[4], three time ranges were considered in the analysis of the particulate matter ($PM_{2.5}$ and PM_{10}) and Carbon Monoxide CO, early morning off-peak hours (4:50–6:30 AM), morning peak hours (6:30-9:10 AM) and afternoon peak hours (3:40-5:40 PM). This study was conducted on December 2004. Along with the particulate matter in the air, CO concentration in PPM was also collected and analyzed in 30 different sites for 15 minute intervals. Regression models were used to determine which sources affect the levels of known pollutants in an area.

The second study by Costales et al.[9] mainly discussed the PM_{10} data of the Baguio Central Business District and its contribution to the health of citizens of Baguio City. The study was published in 2016. The objectives of the study were the identification of the impacts of short and prolonged exposure to air pollutants in the Baguio Central Business District and to estimate the socio-economic cost of the identified health impacts of air pollution from public transportation in the Baguio Central Business District. The study was done by collecting data of hospitals about respiratory tract infections. This data was then used to estimate and predict the socio-economic cost of Baguio's air quality.

There are available data of the particulate matter collected by EMB-CAR(Environment Monitoring Baguio-Cordillera Administrative Region). In our inquiry and visit to EMB-CAR, we were told that they had no data of the Carbon Monoxide concentration of Baguio and their device for collecting data of $PM_{2.5}$ is currently under construction as of April 2019. The only available data they had was for PM_{10}.

2.5 Hardware Used in the Study

2.5.1 The Arduino Uno Micro Controller

Arduino is an open-source computer hardware and software company known for their creating of programmable micro controllers, as stated in their website[2]. The most common of these micro controllers is the Arduino Uno. To be able to use the micro controller, a program must be uploaded to it from their own IDE. Multiple components for this micro controller usually have libraries for ease of use and better understanding of how the component works.

Figure 2.3: Arduino Uno microcontroller (image from Trossen Robotics [34])

2.5.2 The MQ-7 and MQ-135 Sensors

The MQ-7 is a semiconductor sensor that is used for detecting the presence of Carbon Monoxide(CO) in the atmosphere. This sensor is often used in tandem with the MQ-135 for devices used for the analysis of air quality, as used in study by Devarakonda et al.[11]. The sensor has PCB module that has a variable resistor which can be adjusted up to 10 kΩ. 4 pins are included in the PCB module (from left to right with the sensor facing upward). Noted by Vandana and Baweja[36] , this sensor is sensitive to temperature and the humidity of the atmosphere. The values should be adjusted to the factors in the conversion of the analog values to the PPM.

Figure 2.4: MQ-7 sensor used for the collection of CO data (image from Makerlab Electronics website [22])

Figure 2.5: MQ-135 sensor used for the collection of CO_2 data (image from Makerlab Electronics website [23])

As pointed out by Vandana and Baweja [36], the sensor outputs raw analog values that are taken from the reaction of the resistor to certain gases in the air around it. The equations that will be used to extract data from the analog outputs of the sensors are still from study by Vandana and Baweja [36]. These equations are for finding the effects of temperature and humidity to these kinds of sensors which are an improvement on Gironi[16]'s formula and obtaining the PPM concentration values from analog outputs. The load resistance R_L is the resistance value built-in to the PCB module of the sensor. Equation 2.2 below is for converting analog sensor values to sensor resistance R_S.

$$R_S = (\frac{1023}{SensorValue} - 1) * R_L \tag{2.2}$$

Graphs are given by the manufacturer in the datasheet to scale the values pertaining to what gas you want obtain the values of.

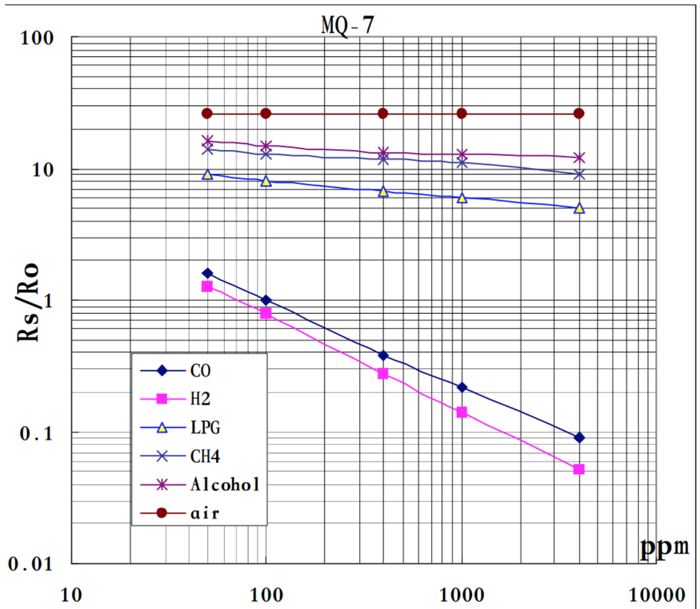


Figure 2.6: The log-linear graph of the equations for the conversion of analog values to concentrations of different gasses in ppm on MQ7 datasheet [27]

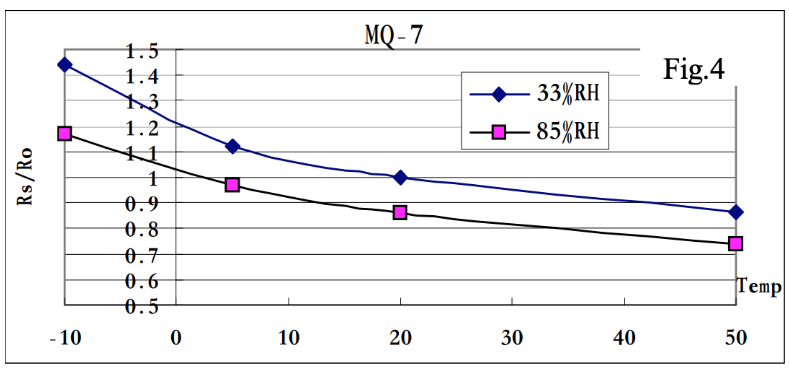


Figure 2.7: The graph of the equation for the sensitivity of the sensor to temperature and relative humidity on MQ7 datasheet [27]

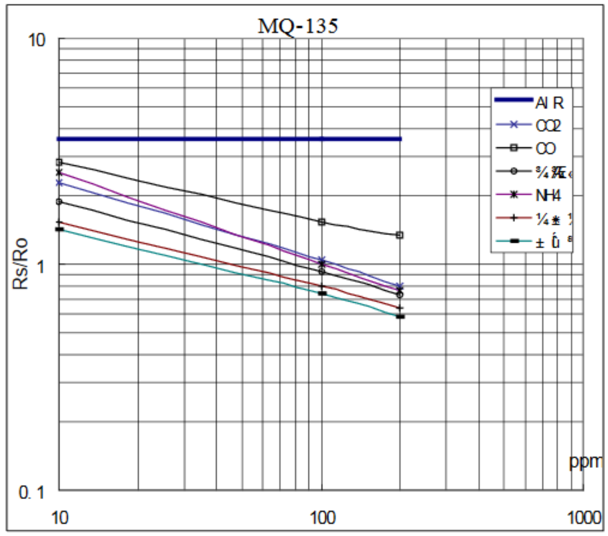


Figure 2.8: The log-linear graph of the equations for the conversion of analog values to PPM on MQ135 datasheet [38]

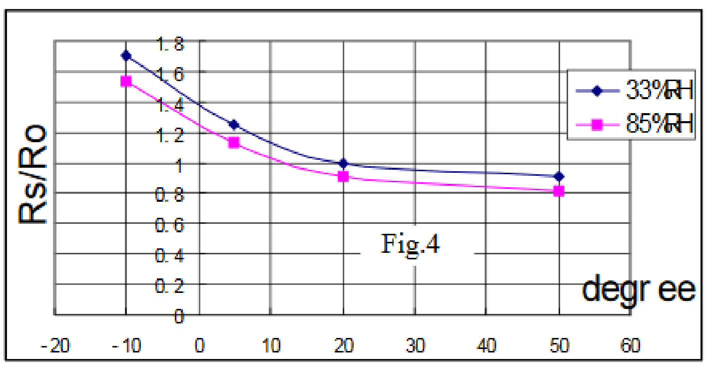


Figure 2.9: The graph of the equation for the sensitivity of the sensor to temperature and relative humidity on MQ135 datasheet [38]

The log-linear graphs for both MQ-7 (figure 2.6) and MQ-135 (figure 2.8) have the lines with the following equation for each type of gas:

$$y = ax^b \tag{2.3}$$

where y is the gas concentration in PPM, a and b are constants, and x is R_0/R_S. To solve for the calibration resistance R_0, analog values of the sensor in acceptable air is needed for equation 2.2 to obtain R_S. The PPM concentration values for acceptable air is based on global air quality standards. The equation 2.4 below is the equation for calibration resistance R_0.

$$R_0 = R_s * \left(\frac{a}{PPM}\right)^{\frac{1}{b}} \tag{2.4}$$

After the calibration resistance R_0 is found, we can find the gas concentration values in PPM using the equation 2.5 below.

$$PPM = a * \left(\frac{R_S}{R_0}\right)^b \tag{2.5}$$

These equations can be applied to both of the sensors. To correct the R_S according to temperature and humidity, we can get points from the graphs provided and interpolate the equation. For these sensors we get the equation of z (R_S scaling factor) as:

$$z = a - bx - cy \tag{2.6}$$

Applying z, x, and y as scaling factor (R_s *Scaling Factor*), temperature in C° (t), and relative humidity(h) respectively, the equation 2.6 would be equation 2.7.

$$R_s\text{Scaling Factor} = a - bt - ch \tag{2.7}$$

The equation for corrected R_S is the equation 2.8 below.

$$\text{Corrected } R_S = \frac{R_S}{R_S\text{Scaling Factor}} \tag{2.8}$$

Another thing to note by Vandana and Baweja[36], the datasheets provided by the manufacturers are incomplete and often hard to decipher since they provided little to no information about the methods of calibration and the reliability of the sensor. Individual studies, like the ones mentioned before, are the most reliable sources of information with these sensors since their discussions on the sensor are often complete and comprehensible.

2.5.3 The Bluetooth Module

The Bluetooth module used in the sensor set up is the HC-05. According to Components101 [7], this module can act as both slave and master. Though, we only use it as a slave since we only need it to request connections to our smartphones since we only need it to send data. A cheaper option to this module is the HC-06 which cannot act as a master but only as a slave. We did not use this module because it was not available through our retailer. Both of the modules are suitable to use in our set up.

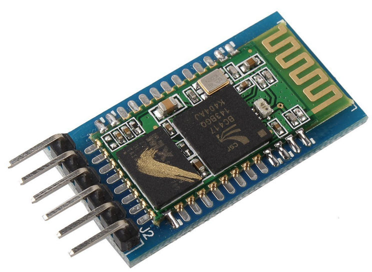


Figure 2.10: The HC-05 Bluetooth Module (image from [25])

2.5.4 DHT11 Temperature and Humidity

In the products page of Components101[6], the DHT-11 is a cheap, basic and digital temperature and humidity sensor. This can be purchased with or without an already made PCB board, complete with the needed resistors. Another option for the temperature and humidity sensor is the DHT-22. It is said that it gives a more accurate reading of temperature and humidity. But, it seemed like in our tests, that the DHT-11 was more than enough for recording the temperature and humidity of the atmosphere.

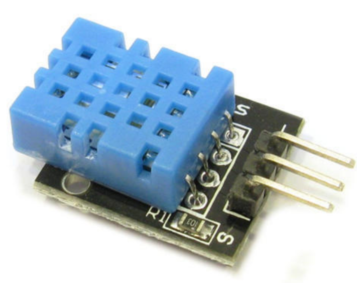


Figure 2.11: DHT-11 temperature and humidity sensor (image from Majju[21])

2.6 MIT App Inventor 2

MIT's App Inventor 2[26] (`ai2.appinventor.mit.edu/`) is an easy and accessible way of creating an Android application for users that do not have the time and knowledge for creating an Android application from scratch. The GUI for this web application is easy to comprehend as it emulates puzzle pieces that connected to functions already provided by the creators of the web application. You can then download the .apk file for you to install your application on your phone or you can download their app that you can use to obtain a real time broadcast of the application you are working on.

2.7 Other Applications Used to Generate Graphs and Schematics

2.7.1 Fritzing (`fritzing.org`)

Fritzing[3] is an CAD (Computer-Aided Design) software for designing electronics such as Arduino and its modules. It is an open source software developed at the University of Applied Sciences of Potsdam. This will be used to draw schematic diagrams for the Arduino modules.

2.7.2 ScribbleMaps.com (`scribblemaps.com`)

The ScribbleMaps[1] website offers a mobile ready, web-based, cross-api, map-authoring platform. The site is owned and operated by 52 Stairs Studio Inc. This will be used to show the satellite overlay with the geo-spatial graph used in this study.

2.8 Spatial Graph Theory and Air Quality

There has not been many studies concerning spatial graph theory and correlating it to air quality. The more common air quality models are designed for predicting the trajectory and behavior of the pollutants as time passes. Most of these numerical predictive models are based off the meteorological and atmospheric data.

In a report by the National Academics of Sciences[24], different models were made for the simulation of the spread of pollutants through an urban area. There are used to identify local hotspots based off high concentrations of these pollutants in the atmosphere. The models simulate the movement of gas through the atmosphere and how their behavior changes when they reach a certain amount. There is also a model that simulates the movement of CO in macroscopic space. The model uses the wind speed and the spatial distribution of the pollutant. This model has been used by cities to assess the effects of expanding roads and large constructions has to air quality.

2.9 Definition of Terms

1. PPM - the unit for concentration. It stands for *parts per million*

2. Acceptable concentration - it is a concentration in PPM unit of either CO or CO_2 in an environment with known clean air

3. Acceptable CO Concentration - According to Cassidy [4], 2 ppm is the typical CO concentration of the Baguio Central Business District. This can be the basis for UP Baguio too, since it is part of it.

4. Acceptable CO_2 Concentration - According to co2.earth [28], 411 PPM is the normal global Carbon Dioxide PPM concentration

5. Morning peak time slot - it is expected in these hours that roads have a high volume of vehicle traffic, for it is when the employees and students go to work and school. In this study, we set it from 7:30 AM to 9:00 AM in the morning. This assumption is from the data of EMB-CAR[4] and the study of the National Academies of Sciences [24].

6. Off peak time slot - it is expected in these hours that roads have a low volume of vehicle traffic, for it is when the employees and students are already in their workplaces and schools. In this study, we set it from 1:30 PM to 3:00 PM in the afternoon. This assumption is from the data of EMB-CAR[4].

7. Afternoon peak time slot - it is expected in these hours that roads have a high volume of vehicle traffic for it is when the employees and students go to home. In this study, we set it from 4:30 PM to 6:00 PM in the afternoon. This assumption is from the data of EMB-CAR[4] and the study of the National Academies of Sciences [24].

Chapter 3

Methodology

3.1 Hardware Specifications

Numerous versions were developed as there were improvements to be made to the previous versions until we came up with a configuration with stable outputs. The final setup was compact, stable, and light.

3.1.1 Progress of Hardware Used

Figure 3.1: The first version of the Arduino module placed inside a food container

The first version of the data collection setup, was more of a test if the hardware worked together, rather than aiming for it to be a compact and effective setup. The two sensors were connected to a LCD screen that printed out the raw values of the sensors. The circuit was installed in a food container. This setup has this circuit diagram:

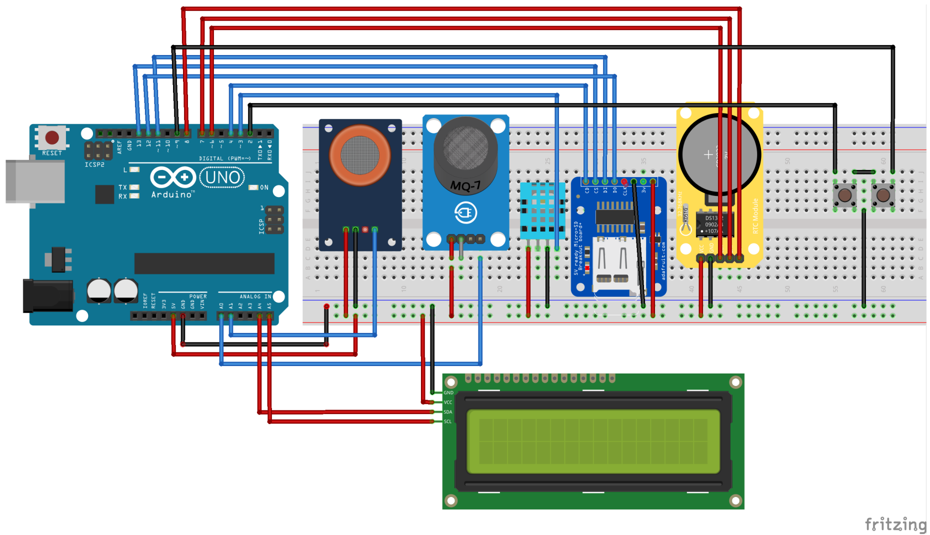


Figure 3.2: The schematic diagram of the second version of the Arduino module made through Fritzing[15]

The first setup of the hardware had numerous things to improve on. For the second version of the setup, the circuit had a Real-Time Clock component that was used for logging the time of the data collection. Other modules were also added such as: a micro-SD card component that logged the data to a CSV file, and a LCD screen to display the data being logged. This setup also had two buttons. One was to scroll though the sensor data in the LCD screen and the other one was to start the data collection timed for five minutes. Two powerbanks were used for this setup as one was not enough in powering all the components in this setup.

Figure 3.3: Second version of the Carbon data collection gadget

The final setup will be thoroughly discussed per component in the preceding sections and its components were mentioned in previous sections in the related literature chapter.

3.1.2 Final Schematic Diagram of the Hardware Used

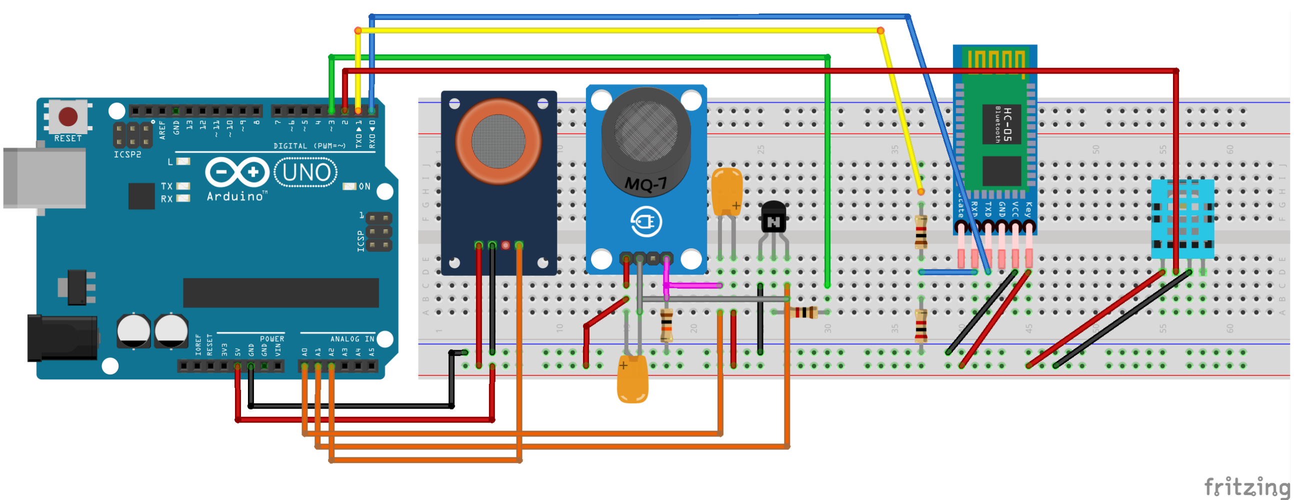


Figure 3.4: Current Schematic Diagram of the Arduino Module made through Fritzing[15]

The schematic diagram of the Arduino module evolved from a micro-SD card data collection to Bluetooth-Smartphone collection. The current schematic diagram in figure 3.4 shows the connections of the Arduino components to a breadboard. It incorporates the mechanism of measurement phase and heating phase required by MQ-7 sensor. The series of capacitors, transistors, and resistors for this mechanism came from the schematic proposed by Ultimate Robotics[19].

Figure 3.5: The current version of the Arduino Module inside a Green First Aid Kit Box

3.2 Sensor Calibration

3.2.1 Calibration Resistance R_0

The following resistance values and clean air analog values along with their temperature and humidity were obtained from the two Arduino modules.

Table 3.1: Necessary data for calibration sensor resistance R_0 for both Arduino 1 and 2

Arduino Sensor	Resistance values in Ω	Analog Values	Temperature	Humidity
Arduino 1 MQ-7	2503.05	262.53	27.95	66.40
Arduino 1 MQ-135	2595.33	253.71	27.95	66.40
Arduino 2 MQ-7	1466.97	252.3	27.75	64.43
Arduino 2 MQ-135	1466.97	292.79	27.75	64.43

The values on table 3.1 were applied to equation 2.4 on chapter 2 to get the calibration sensor resistance R_0 for both Arduino modules.

3.2.2 Equation Fit Constants for Graphs in Sensor Datasheets

To find the constants, the points in the given log-linear and two-variabled graph of both sensors created a fit with equations $y = ax^b$ and $z = a - bx - cy$ respective of the graph. The equation $y = ax^b$ is for finding the gas concentration while the equation $z = a-bx-cy$ is for finding the scaling factor for the corrected sensor resistance value. The points were fitted using Matlab's Curve Fitting App and gave the following constants.

Table 3.2: Constants for the equation $y = ax^b$ and $z = a - bx - cy$

Sensor	Equation	a	b	c
MQ-7(CO)	$y = ax^b$	88.572	-1.5291	N/A
MQ-135(CO_2)	$y = ax^b$	109.25	-2.5964	N/A
MQ-7(CO)	$z = a - bx - cy$	1.3497	0.0079989	0.0033406
MQ-135(CO_2)	$z = a - bx - cy$	1.4812	0.011763	0.0022188

3.3 Development of Data Gathering Software

3.3.1 Arduino

The program for the Arduino was uploaded on the microchip and coded using their IDE. The program mainly composes of sending the analog data of the Arduino through

Bluetooth to the smartphone.

3.3.2 Android App

An android app was also developed for establishing the Bluetooth connection, timing of the data collections, the data collection itself, displaying the values, and saving the data into CSV files for later processing. The app was created using MIT's App Inventor 2[26]. App Inventor 2 is a free IDE for easy and accessible android app development available for the general public.

3.4 Data Gathering

3.4.1 Node Selection

The UP Baguio campus has three colleges that have their own buildings namely, Kolehiyo ng Agham Building and Iskolar ng Bayan Building for College of Science (CS), CSS-CSC Building for College of Social Sciences (CSS) and CAC Building for College of Arts and Communication (CAC).

In selecting the nodes for the study, areas with frequent traffic of students were considered. Nodes are then connected with edges when they are directly accessible by foot from each other. Fifteen nodes were selected and numbered by their order of data collection. Note that, we also included nodes are that near roads. This is to see the contributions of outside emissions to the atmospheric Carbon Oxide of the campus.

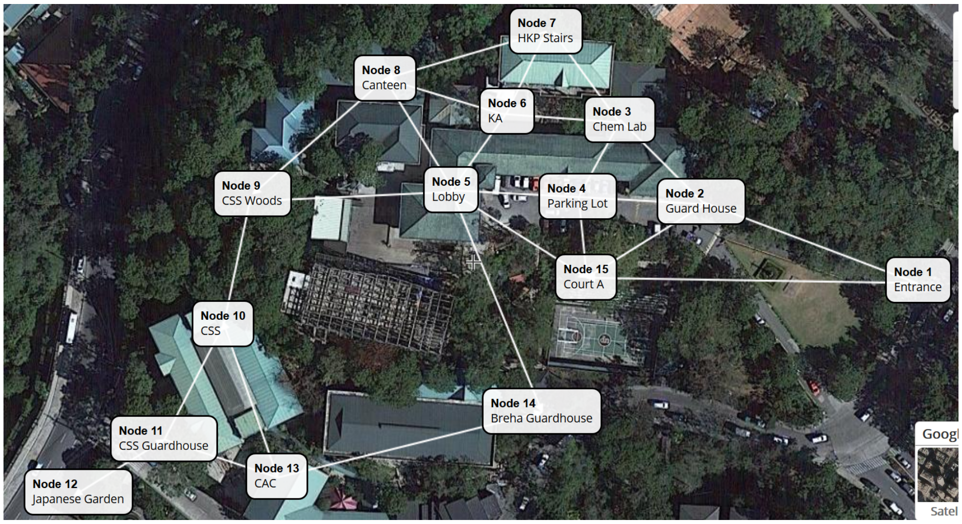


Figure 3.6: Geo-spatial graph of the Nodes in UP Baguio underlayed with a satellite image of the campus made through ScribbleMaps[1]

Table 3.3: Node number and specific locations of nodes where the data is collected

Node Number	Location
1	Main Entrance
2	Guardhouse
3	Bio Chemical Laboratory
4	Parking Lot
5	Main Lobby
6	Kolehiyo ng Agham(KA) Quadrangle
7	Human Kinetics Program Stairs
8	Canteen
9	College of Social Sciences(CSS) Woods
10	CSS Building
11	CSS Guardhouse
12	Japanese Garden
13	College of Arts and Communication (CAC)
14	Breha Gate
15	Court A Bleachers

3.4.2 Timings, Dates and Days

In the days of collections, three days were considered. In 2017, UP Baguio launched a campaign called *Car-less Wednesdays*, as reported on an article in the UP Baguio

Website[20]. Where every Wednesday, automobiles are not allowed to enter the UP Baguio Parking Lot but are only allowed to drop off their passengers in the loading and unloading zone near the guardhouse. This program aims to help in improving the air quality of Baguio. Because of the large, vacant parking lot, PE classes for Petanque are held in the open parking lot. Though, there may be no vehicles in the lot, the clean-up of the sand and gravel used in the sport activity may generate particulate matter, that can worsen air quality in the vacant lot and the buildings adjacent to it. But, in this study, we cannot determine this since, we will only be collecting the CO and CO_2 PPM which are only generated by emissions of vehicles and other carbon-fueled combustion. Next is we considered Thursday to represent the "normal" weekdays and Saturday for the weekends.

In terms of time, we take into consideration the peak and off peak time slots based of human and vehicle traffic coming in and out of the campus. For the peak time slot, two were picked. One in the morning (7:30-9:00 AM) and the other in the afternoon (4:30-6:00 PM) since it is the arrival and departure of most employees and students in the campus, respectively. One off peak time slot (1:30-3:00 PM) was examined. The time slots is patterned towards the data of EMB-CAR in 2012 for the hourly PM_{10} levels in Baguio CBD coming from the study of Costales et al.[9]. For each of the nodes, five minutes were spent in the area of the node for the collection of the data by the sensors. The MQ-7 CO sensor needed time to reheating time of 90 seconds which required a higher voltage and was ready for 60 seconds of data collection after the fact. For the sensor for the CO_2, the MQ-135, it collected for the whole five minutes.

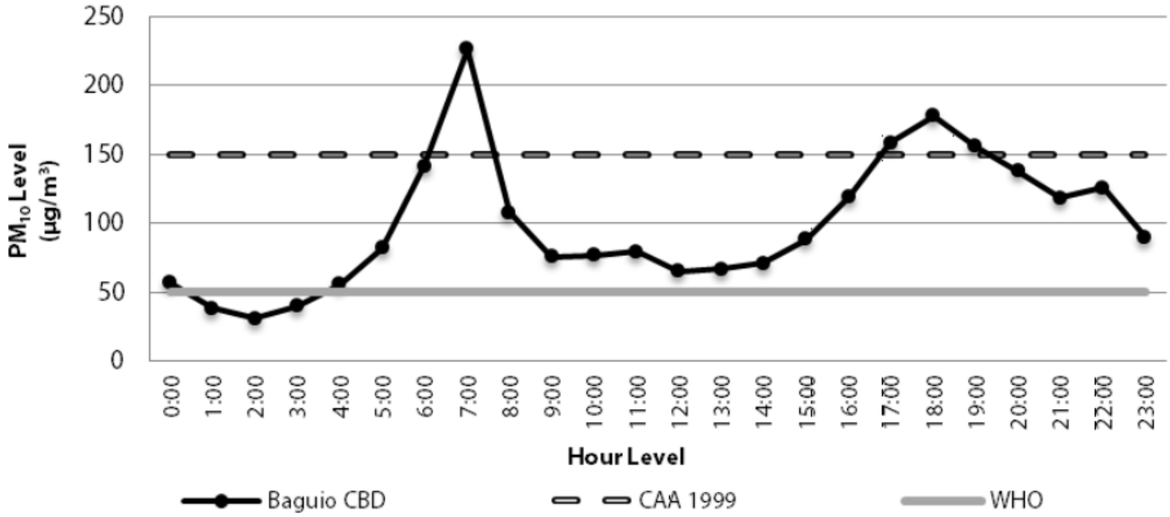


Figure 3.7: Levels of PM_{10} per hour averaged over a week in Baguio BCD from Costales et al.[9]

3.4.3 Twenty-Four Hour Data Collection

One of the Arduino sensor module was strapped to the windowsill of the ComSci Lab 1 in the *Iskolar ng Bayan* building. Four days were considered (Wednesday-Saturday) for the full twenty-four hour values of both the CO and CO_2 data. The sensor module was modified so that the CO and CO_2 raw data will be stored on a micro-SD card through a micro-SD card module. For the power of the Arduino module, an extension cord with an outlet connected inside the COMSCI Lab 1 was used.

3.5 Proposed Target Set Selection Algorithms Used in the Study

We define a piece-wise function that we will input our PPM values (in $g(v)$ for CO or $h(v)$ for CO_2) for each vertex v which will output threshold values $t(v)$ assigned to the vertex that was input.

$$t_{CO}(v) = \begin{cases} 0 & g(v) \leq 2 \\ 1 & 2 < g(v) \leq 3 \\ 2 & 3 < g(v) \leq 4 \\ 3 & 4 < g(v) \leq 5 \\ 4 & 5 < g(v) \leq 6 \\ 5 & 6 < g(v) \leq 7 \\ 6 & g(v) > 7 \end{cases}$$

$$t_{CO_2}(v) = \begin{cases} 0 & h(v) \leq 400 \\ 1 & 400 < h(v) \leq 600 \\ 2 & 600 < h(v) \leq 800 \\ 3 & 800 < h(v) \leq 1000 \\ 4 & 1000 < h(v) \leq 1200 \\ 5 & 1200 < h(v) \leq 1400 \\ 6 & h(v) > 1400 \end{cases}$$

Note that these functions are only for our network graph of the campus. These functions may have additional or less values for thresholds depending on connected the nodes in the graph are and how many nodes you have in your graph.

3.5.1 Parameters of the proposed algorithm

With the algorithms discussed earlier and the model we have in mind, we need to incorporate the PPM values of CO ($g(v)$) and CO_2 ($h(v)$) to the existing model. We will use a simple graph as the framework of our model with $G = \{V, E\}$ as per the previous model we have introduced. Since our aim is to reduce the PPM values of each nodes to acceptable PPM values, it's fair to assume that threshold can be modified in order to accommodate the PPM values we have collected. We do this by applying the two piece-wise defined functions to our PPM values mentioned earlier. Thus, $t(v)$ will be either t_{CO} or t_{CO_2} depending on the selected gas.

Algorithm 3 Proposed TSS Algorithm

Require: $G = (V, E)$, Thresholds $t(v)$ for $v \in V$

Ensure: Target Set S

```
S = ∅
U = V
for all v ∈ v do
    δ(v) = d(v)
    k(v) = t(v)
    N(v) = Γ(v)
end for
while U ≠ ∅ do
    if there exists v ∈ U s.t k(v) = 0 then
        for all u ∈ Nv do
            k(u) = max(k(u) − 1, 0)
        end for
    else
        if  there exists v ∈ U s.t δ(v) ≤ k(v) then
            S = S ∪ {v}
            for all u ∈ N(v) do
                k(u) = k(u) − 1
            end for
        else
            v = argmax_{u∈U}{ k(u) / (δ(u)(δ(u)+1)) }
        end if
    end if
    for all u ∈ N(v) do
        δ(u) = δ(u) − 1
        N(u) = N(u) − v
    end for
    U = U − v
end while
```

Algorithm 4 Proposed Greedy Algorithm

Require: $G = (V, E)$, Thresholds $t(v)$ for $v \in V$

Ensure: Target Set S

```
S = ∅
U = V
for all v ∈ v do
    δ(v) = d(v)
    k(v) = t(v)
    N(v) = Γ(v)
end for
while U ≠ ∅ do
    v = argmax_{u∈U} {k(u)}
    if k(v) > 0 then
        S = S ∪ {v}
    end if
    for all u ∈ N(v) do
        δ(u) = δ(u) − 1
        N(u) = N(u) − v
    end for
    U = U − v
end while
```

Variables used in the proposed algorithms:

- S: The resulting target set.
- $d(v)$: Degree of vertex v.
- $t(v)$: Threshold of vertex v.
- $\Gamma(v)$: Neighbor set of vertex v.
- $g(v)$: CO PPM value of vertex v.
- $h(v)$: CO_2 PPM value of vertex v.

Proposed TSSA example

The proposed TSS algorithm is pretty much the same with the original. The only difference is the proposed algorithm has PPM values as input that will be converted to threshold values compared to the original which had direct values as thresholds. The following example is similar to the example 2.1 on chapter 2. It also has the same solution.

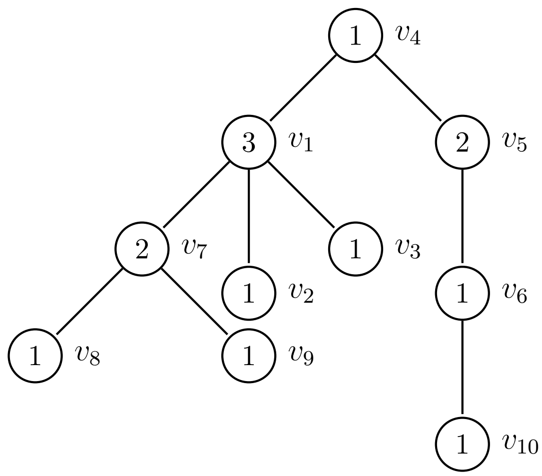


Figure 3.8: A tree with 10 vertices where the number inside the circle is the vertex threshold ($t(v)$).

Vertex v_i	Degree d_i^{in}	Threshold t_i	$TSSmax(v)$	CO PPM	CO_2 PPM
v_1	4	3	0.15	4.27	877.31
v_2	1	1	0.5	2.38	472.94
v_3	1	1	0.5	2.69	479.73
v_4	2	1	0.16667	2.32	477.56
v_5	2	2	0.3333	3.56	677
v_6	2	1	0.16667	2.97	429.18
v_7	3	2	0.1667	3.73	688.1
v_8	1	1	0.5	2.75	471.13
v_9	1	1	0.5	2.47	423.97
v_{10}	1	1	0.5	2.88	459.71

Proposed Greedy TSS Algorithm Example

The proposed Greedy TSS Algorithm always selects the node that has the largest threshold value and if the threshold value is greater than zero it will be added to the target set. Unsurprisingly, the proposed greedy algorithm acts the same with the original in the example 2.2. The example below has CO and CO_2 values added and has the same solution with example 2.2.

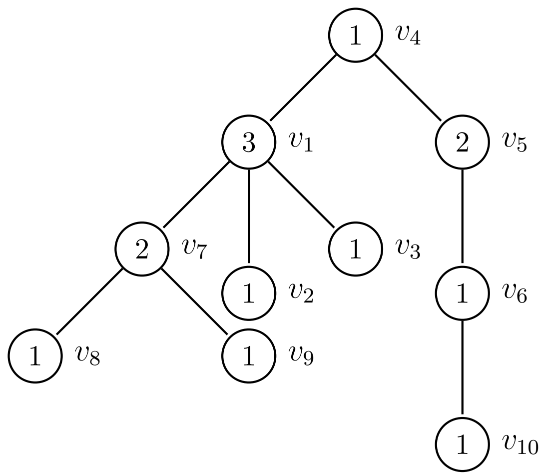


Figure 3.9: A tree with 10 vertices where the number inside the circle is the vertex threshold ($t(v)$).

Vertex v_i	Degree d_i^{in}	Threshold t_i	CO PPM	CO_2 PPM
v_1	4	3	4.27	877.31
v_2	1	1	2.38	472.94
v_3	1	1	2.69	479.73
v_4	2	1	2.32	477.56
v_5	2	2	3.56	677
v_6	2	1	2.97	429.18
v_7	3	2	3.73	688.1
v_8	1	1	2.75	471.13
v_9	1	1	2.47	459.71
v_{10}	1	1	2.88	459.71

3.6 Data Processing Program

A data processing program was made to convert the gas concentration values from analog values to the corrected PPM based of temperature and humidity. This was done in Java Programming Language. The program has the following functions:

1. To display a set of data in a Graphical User Interface according to date and time of the collection.
2. To compute for the average and actual gas concentration values on certain data collections of date and time.
3. To implement the proposed TSS and Greedy TSS algorithms on the gas concentration data

The computations from the data processing program was then imported into Matlab to generate plots such as time series graphs and bar graphs.

Chapter 4

Results and Discussion

4.1 Trends

4.1.1 CO Trend in the Same Time Slot in Different Days

CO Trend in Morning Peak Time Slot

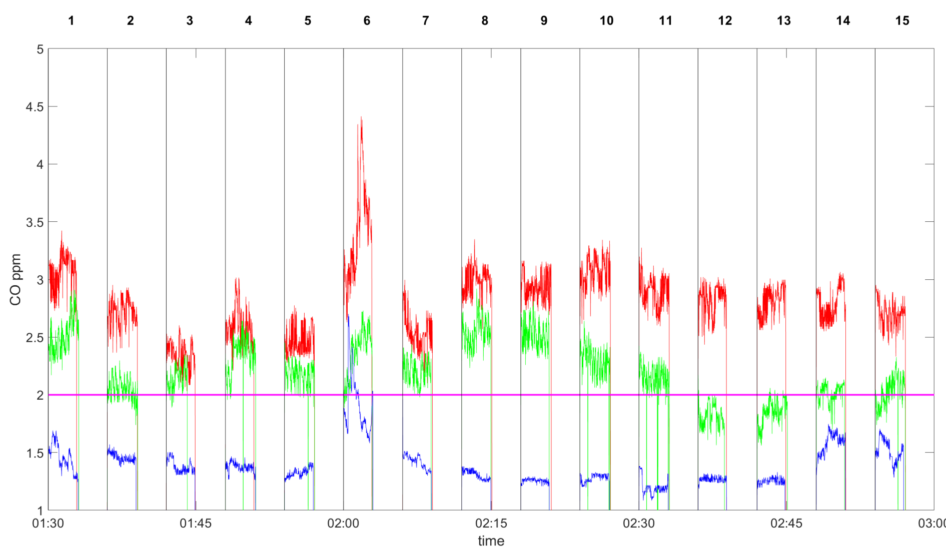


Figure 4.1: Trend of CO in each node (numbered on top) through time in different days of the week at 7:30-9:00 AM. Wednesday in Blue, Thursday in Green, Saturday in Red, Magenta - Acceptable CO PPM Level

The car-less Wednesday showed a significantly lower CO concentration compared to the other days. This is supported by the fact that CO particles come from vehicle emissions. It turns out that Saturday has the highest CO concentrations among other days because there were multiple events that happened on the campus that allowed parking vehicles on parking lot. On that day, there was a Baguio-wide 3x3 Basketball tournament held on Court A, a campaign rally on Athletic bowl which is near CSS Woods, and debate tournament on CSS building.

CO Trend in Afternoon Off-peak Time Slot

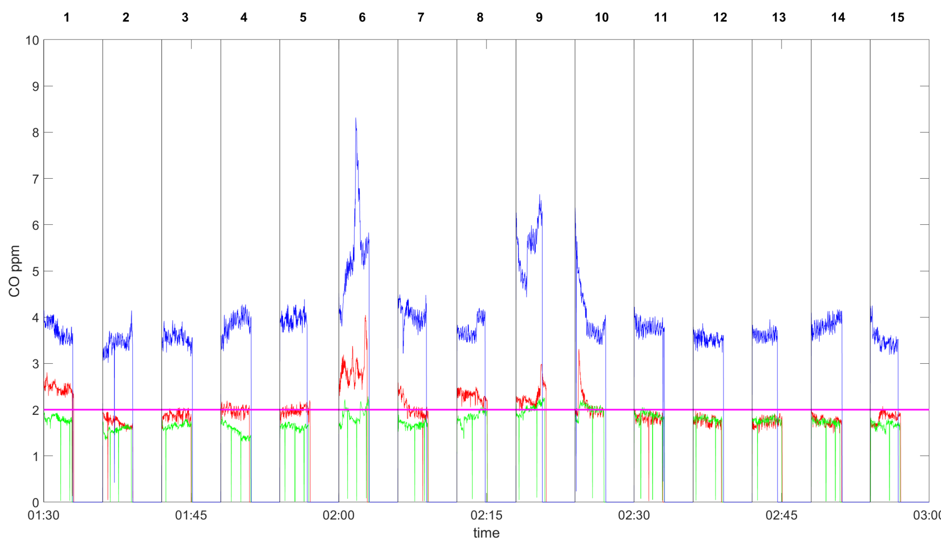


Figure 4.2: Trend of CO in each node (numbered on top) through time in different days of the week at 1:30-3:00 PM. Wednesday in Blue, Thursday in Green, Saturday in Red, Magenta - Acceptable CO PPM Level

This time, car-less Wednesday got the highest CO PPM values among the other days. The effect of the car-less campaign seems to have worn off because of the high CO concentration on surrounding roads. Saturday and Thursday values are almost equal in concentrations. The number of people inside the campus on this Saturday was higher than expected due to the events held.

CO **Trend in Afternoon Peak Time Slot**

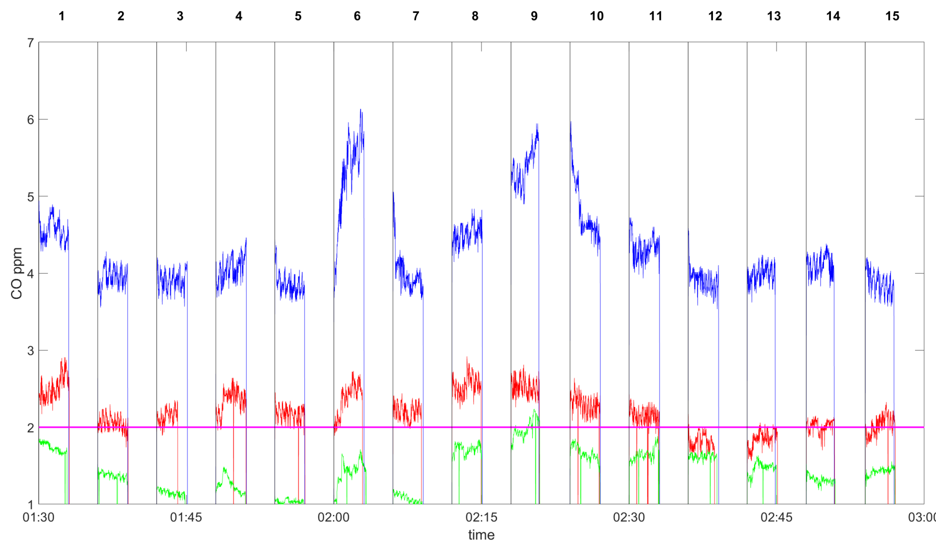


Figure 4.3: Trend of CO in each node (numbered on top) through time in different days of the week at 4:30-6:00 PM. Wednesday in Blue, Thursday in Green, Saturday in Red, Magenta - Acceptable CO PPM Level

The worn off effect of the car-less Wednesdays campaign continues to make the high concentration on Wednesday afternoon peak time slot. The events inside the campus on this Saturday concluded. Their vehicles which were parked on the UP Baguio parking lot, are for their way outside the campus and contributed to the higher concentration of CO on this time slot.

There is an apparent trend at node 6 with the rise in the Carbon Monoxide levels. Node 6 is the quadrangle of the *Kolehiyo ng Agham* building. This area is surrounded by air conditioning units, but air conditioning units do not emit CO, according to quick-solutions air[29], so we are not able to blame this on the air conditioners surround this area for its CO concentration. The other possibility is that, this area is near the exhaust fan of the chemical laboratories of the Biology department.

4.1.2 CO Trend in the Same Day in Different Time Slots

CO Trend in Saturday

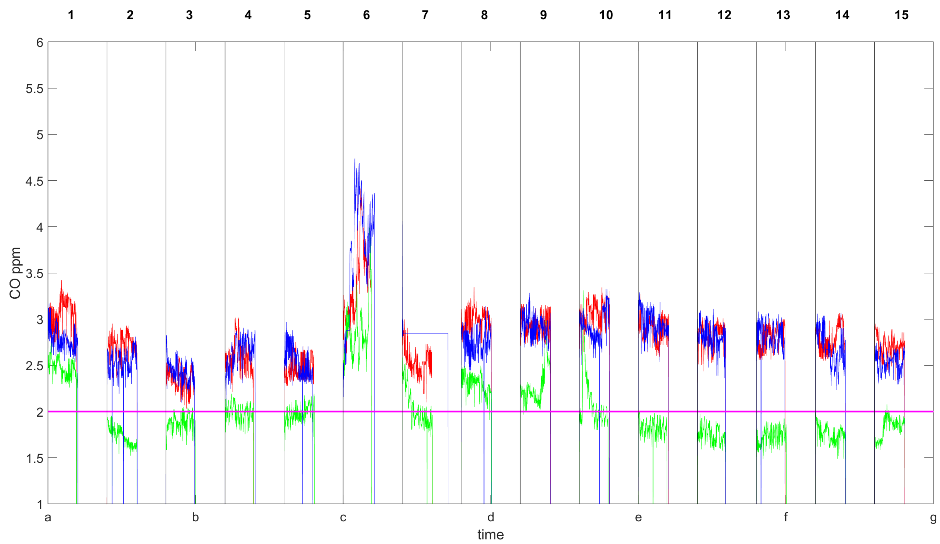


Figure 4.4: Trend of CO in each node (numbered on top) through time in different time slots at Saturday.a and g are the start and end collection times. 7:30-9:00 AM in Red, 1:30-3:00 PM in Green, 4:30-6:00 PM in Blue, Magenta as Acceptable CO PPM Level

On this day, the time slots showed their expected behaviors. The peak time slot in the morning and afternoon had higher CO concentrations than the off peak afternoon time slot. We see similar trends between the 3 time slots in the study. There does not seem to be an increase in the PPM as time increases.

CO Trend in Car-less Wednesday

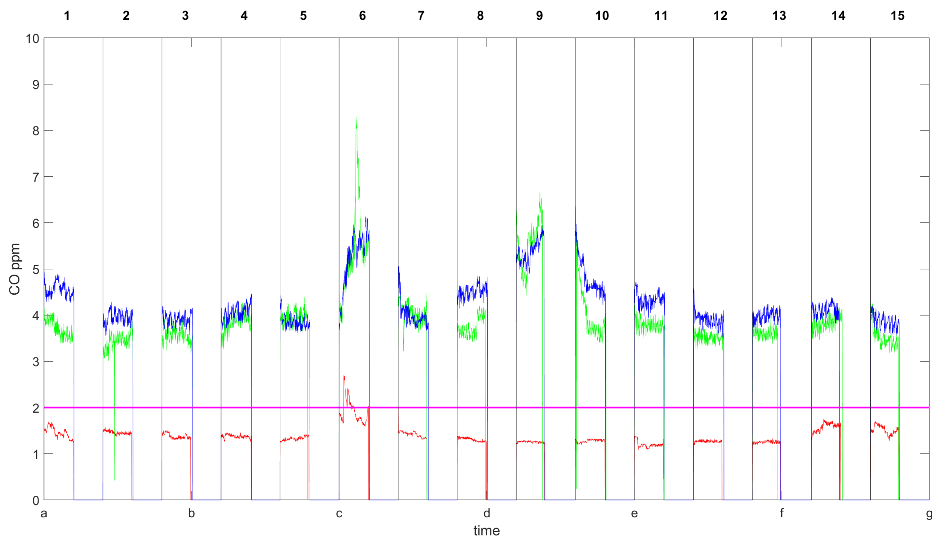


Figure 4.5: Trend of *CO* in each node (numbered on top) through time in different time slots at Wednesday.*a* and *g* are the start and end collection times. 7:30-9:00 AM in Red, 1:30-3:00 PM in Green, 4:30-6:00 PM in Blue, Magenta as Acceptable CO PPM Level

In the morning peak time slot, the Car-less Wednesday campaign has a significant effect in lowering the *CO* concentrations of the campus. This effect wore off because, through the afternoon, the campus become a Carbon Monoxide 'sink' which siphons the high concentrations of the roads outside the campus.

CO Trend in Thursday

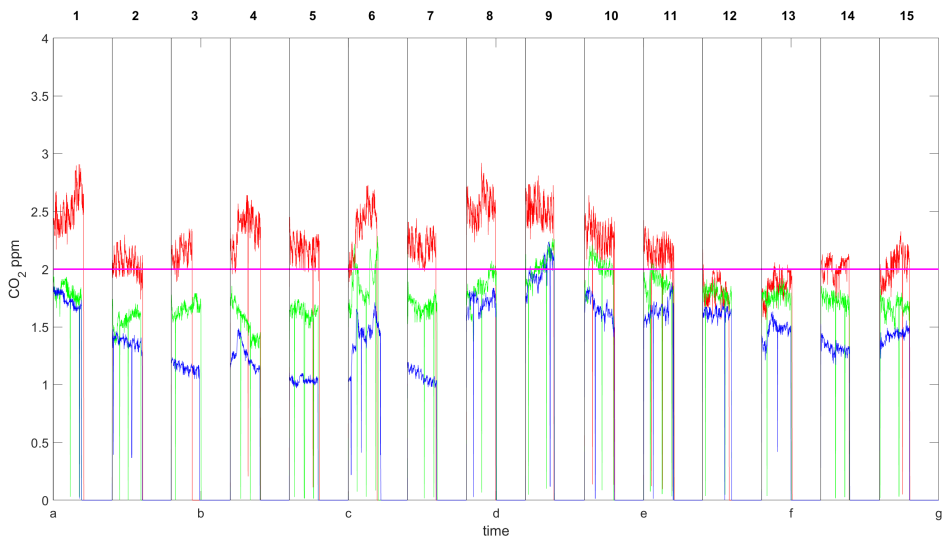


Figure 4.6: Trend of CO in each node (numbered on top) through time in different time slots at Thursday.a and g are the start and end collection times. 7:30-9:00 AM in Red, 1:30-3:00 PM in Green, 4:30-6:00 PM in Blue, Magenta as Acceptable CO PPM Level

The expected behavior of the time slot of data collection do not manifest because of the weather disturbance on the night before the data collection day.

4.1.3 CO_2 Trend in the Same Time Slot in Different Days

CO_2 Trend in Morning Peak Time Slot

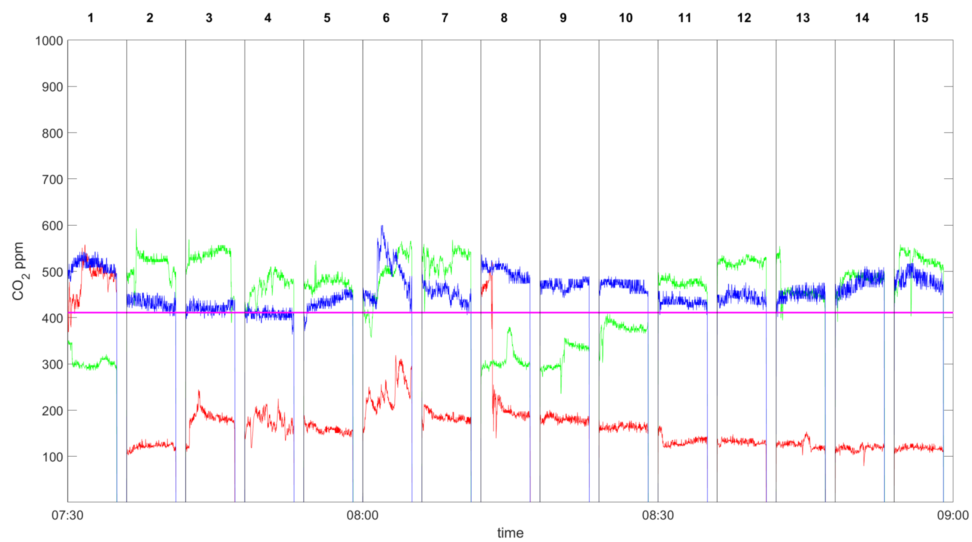


Figure 4.7: Trend of CO_2 in each node (numbered on top) through time in different days of the week at 7:30-9:00 AM. Blue-Wednesday, Green-Thursday and Red-Saturday, Magenta as Acceptable CO_2 PPM Level

CO_2 gas is a part of the human respiratory process. The more humans present in an area, the higher CO_2 gas concentration will be. So, for weekdays, Wednesday and Thursday in particular, higher concentrations of CO_2 is seen. The volume of people that attended early in the event might not be as many as the students, faculty members, and staffs that required early mornings to go to school on weekdays.

CO_2 Trend in Afternoon Off-peak Time Slot

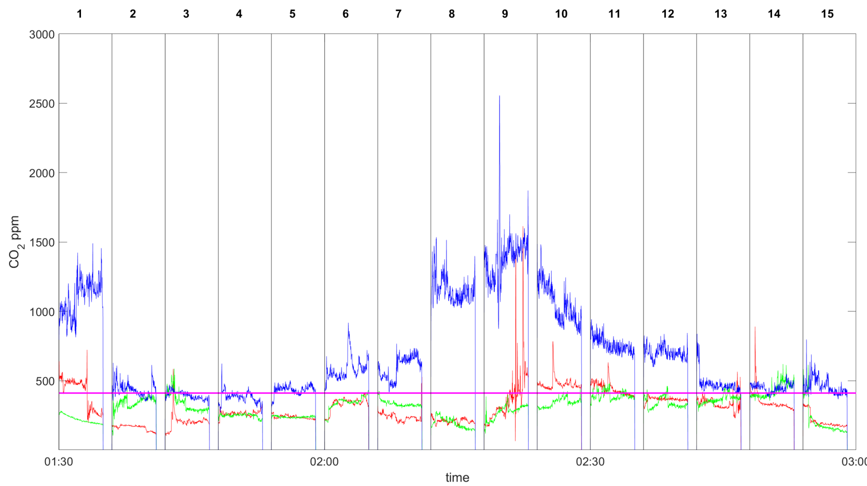


Figure 4.8: Trend of CO_2 in each node (numbered on top) through time in different days of the week at 1:30-3:00 PM. Blue-Wednesday, Green-Thursday and Red-Saturday, Magenta as Acceptable CO_2 PPM Level

In some areas, the effect of the Car-less Wednesday campaign wore off. The surrounding areas had high concentrations. These are nodes 8 and 9, which are the UPB Canteen and CSS Woods respectively. The UPB Canteen has its maximum capacity during lunch time, thus there are residual CO_2 particles after lunch, particularly from 1:30 PM to 3:00 PM. For the case of CSS woods, it directly oversees the Governor Pack Road that might have contributed to the high CO_2 recording in this area. Most of the nodes on Thursday and Saturday are below the acceptable CO_2 concentration level.

CO_2 **Trend in Afternoon Peak Time Slot**

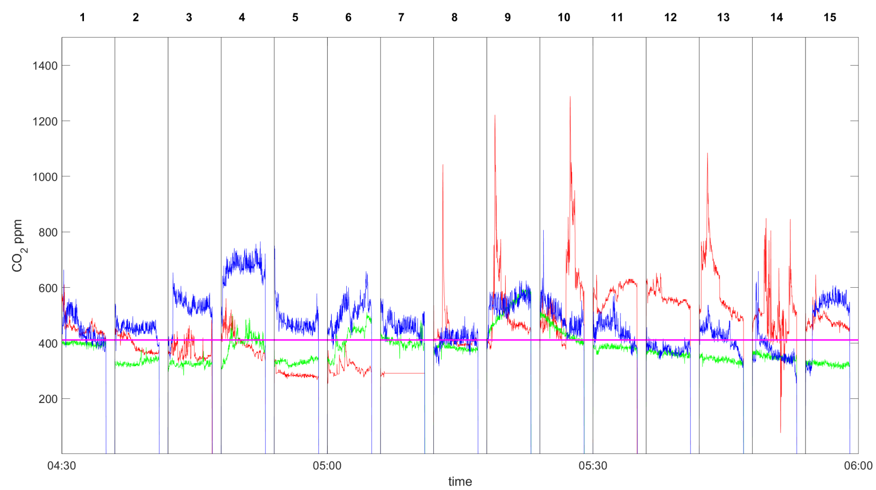


Figure 4.9: Trend of CO_2 in each node (numbered on top) through time in different days of the week at 4:30-6:00 PM. Blue-Wednesday, Green-Thursday and Red-Saturday, Magenta as Acceptable CO_2 PPM Level

There does not seem to be a definite trend as time increases in the graph. The only noticeable behavior of the CO_2 PPM values through time in the hour and a half time range of data collection is that, the values remain stable in the time slots they have. There are influxes in the data when the nodes are in an indoor environment. Node 8, UP Baguio Canteen is the typical cafeteria in an enclosed environment where most of the students gather. This means that human CO_2 emissions will be high in this area as it has a high count of civilians and it is in an indoor area. The Wednesday (blue) line graph is above most of the other graphs in the plot.

4.1.4 CO_2 Trend in the Same Day in Different time Slots

CO_2 trend in Saturday

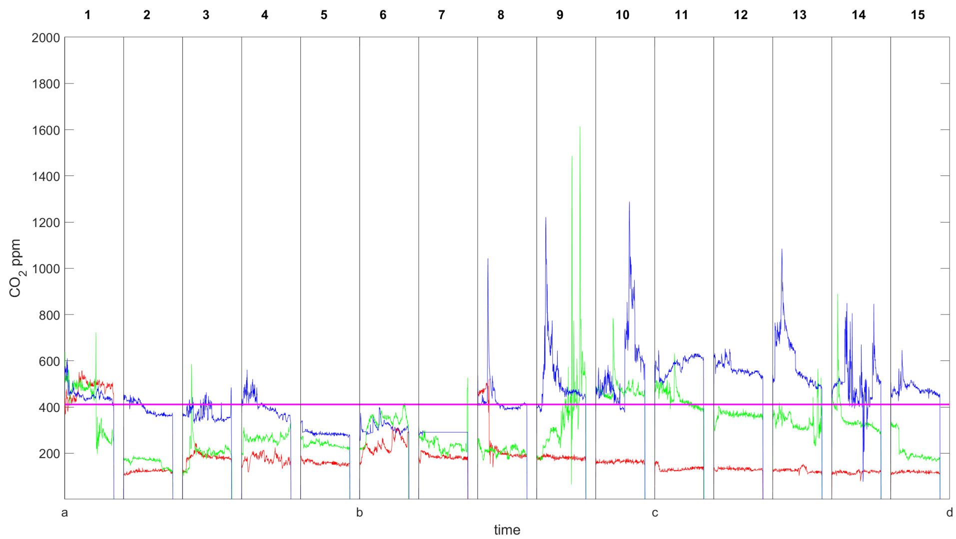


Figure 4.10: Trend of CO_2 in each node (numbered on top) through time in different time slots at Saturday.a and d are the start and end collection times. 7:30-9:00 AM in Red, 1:30-3:00 PM in Green, 4:30-6:00 PM in Blue, Magenta as Acceptable CO_2 PPM Level

Most of the nodes are below the acceptable CO_2 concentration especially during the morning peak time slot. The general trend as the day goes by is the increase in the CO_2 concentration. Afternoon off peak time slot have few nodes above the acceptable CO_2 concentration and more nodes reached above the acceptable CO_2 line on the Afternoon peak time slot.

CO_2 Trend in Car-less Wednesday

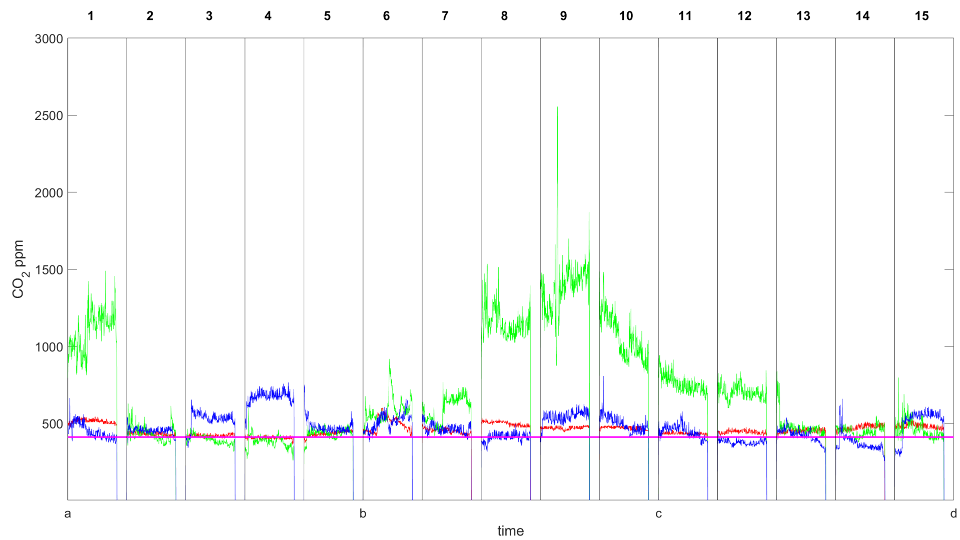


Figure 4.11: Trend of CO_2 in each node (numbered on top) through time in different time slots at Wednesday.a and d are the start and end collection times. 7:30-9:00 AM in Red, 1:30-3:00 PM in Green, 4:30-6:00 PM in Blue, Magenta as Acceptable CO_2 PPM Level

Most of the CO_2 concentration during this day has above acceptable CO_2 concentration. Nodes 8 and 9 have significantly higher CO_2 concentration during the afternoon off peak time slot. These nodes are the UPB Canteen and CSS woods respectively.

CO_2 Trend in Thursday

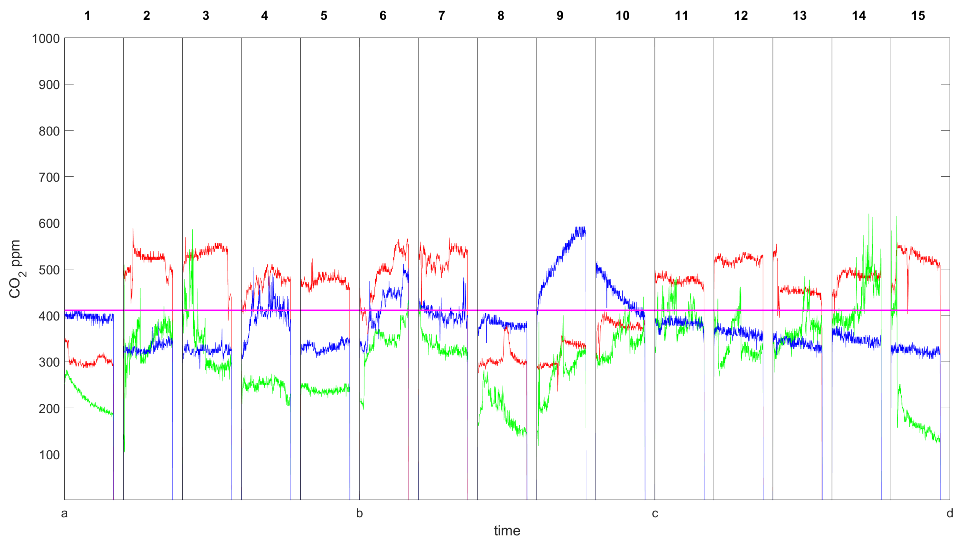


Figure 4.12: Trend of CO_2 in each node (numbered on top) through time in different time slots at Thursday.a and d are the start and end collection times. 7:30-9:00 AM in Red, 1:30-3:00 PM in Green, 4:30-6:00 PM in Blue, Magenta as Acceptable CO_2 PPM Level

The behavior of the time slot of data collection is uncertain because of the weather disturbance on the night before the data collection day. But still, Node 9 during the afternoon peak time slot has the highest CO_2 concentration through the day.

4.2 Comparison of Different Conditions

4.2.1 Comparison of the Days of the Week per Node

CO

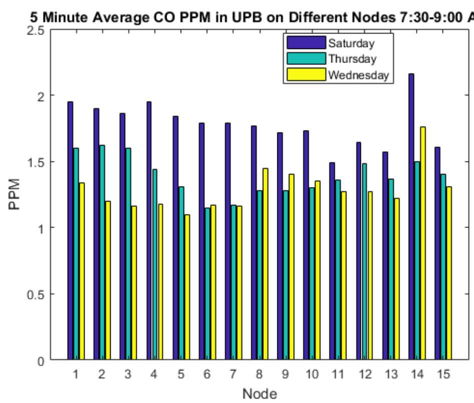


Figure 4.13: Comparison between the five minute *CO* PPM from different time slots (Saturday)

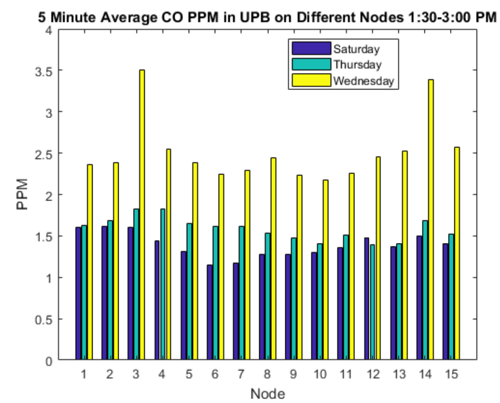


Figure 4.14: Comparison between the five minute *CO* PPM from different time slots (Thursday)

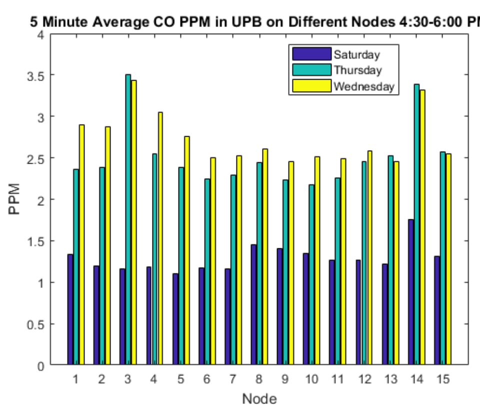


Figure 4.15: Comparison between the five minute *CO* PPM from different time slots (Wednesday)

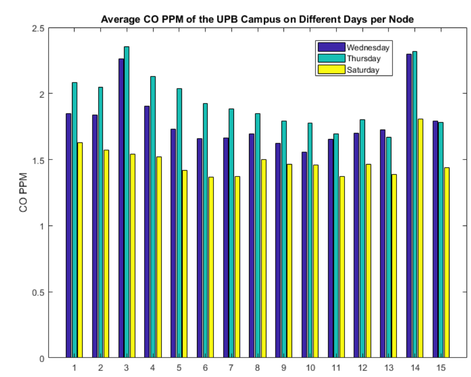


Figure 4.16: Bar graph of the average of all *CO* PPM data collected at each node on a certain day compared to other days.

From what we see in comparing the different days of *CO* PPM values for each node, node 14 (Breha Gate) consistently gave the highest amount of PPM for all 3 days of collection. This is because the gate is near an long uphill road. This uphill is often hard for jeepneys and old vehicles to climb and will need to push the gas harder compared to flat roads. Thus, making their engine use more gas and emit more smoke that contribute the CO PPM which is mainly emissions from fossil fuels. On Mondays, this road is where they monitor to see any potential candidates for smoke belching. If any are spotted they have to pass an emission test near the main gate of UP Baguio. Also, it is worth noting that node 12 (Japanese Garden) gave a low amount of CO PPM even though this node is the bottom of the inclined road of node 14. This justifies that the uphill of the road is the main contributor in triggering vehicles to produce more smoke. This result seems troubling as just across from the gate is the women's dormitory of UP Baguio, where many students and even professors live. Students exposed to these conditions everyday are more susceptible to respiratory problems later on their lives[9].

Another notably high value node is node 3 (Chemical Laboratory). This may be due to the fact that the sensor does not detect CO alone. So, on the weekdays, the output values of the sensor is high, mainly not because of the Carbon Monoxide in the area but other gases that are maybe present in the chemicals the students use for their experiments. This is fine since biology students, even though they are exposed to these chemicals for a long period of time, are equipped with masks and the proper equipment and the laboratory has exhaust fans which lessens the blow of these gases to their health by regulating the air inside the laboratory.

The nodes with less value of PPM are nodes that are deeper into the campus and far from the nearby roads. For example, node 9 (CSS Woods) is located where it is far from the main roads that circumscribe the campus and is surround by a plethora of towering trees and plants.

CO_2

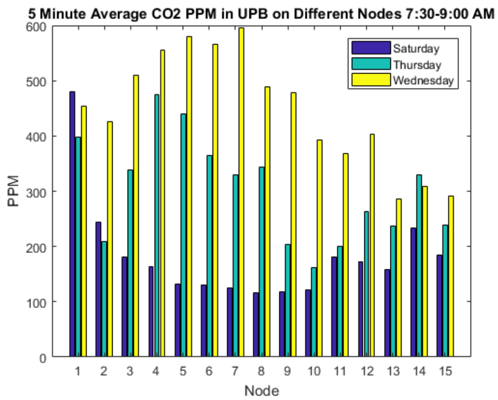


Figure 4.17: Comparison between the five minute CO_2 PPM from different time slots (Saturday)

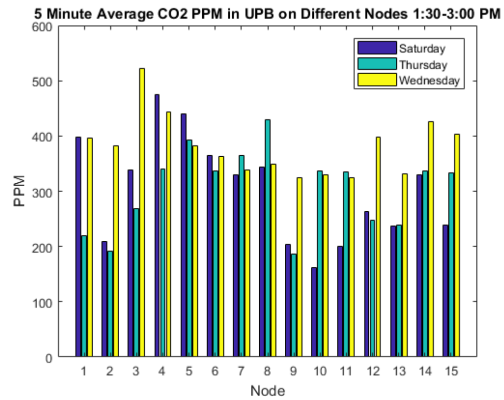


Figure 4.18: Comparison between the five minute CO_2 PPM from different time slots (Thursday)

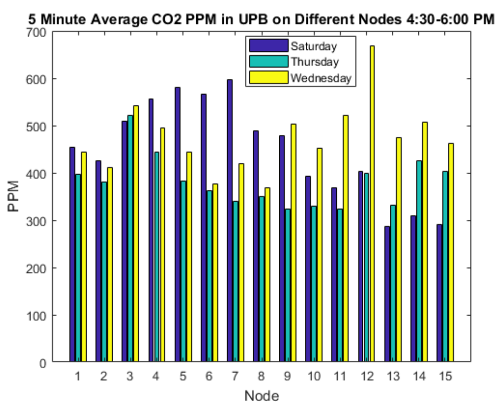


Figure 4.19: Comparison between the five minute CO_2 PPM from different time slots (Wednesday)

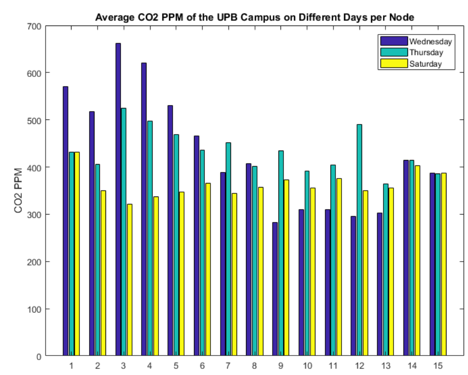


Figure 4.20: Bar graph of the average of all CO_2 PPM data collected at each node on a certain day compared to other days.

For the CO_2 PPM value of the different days per node, nodes 3, 4 and 5 gave high values. Note that these nodes are in or near the parking lot of the campus. The data for the Wednesdays for nodes 4 and 5 seems odd since there are no vehicles in the parking lot but instead had P.E. classes for Petanque. The data for Saturday shows that nodes that are near the road have higher concentrations of CO_2 PPM compared to those far from roads like nodes 2-10, which are nodes inside the different buildings of the campus.

In terms of data reliability, the CO sensor gave more consistent data compared to the CO_2 sensor. This can be said since we can see similar trends for the CO throughout the different days and different nodes.

4.2.2 Comparison of the Days of the Week

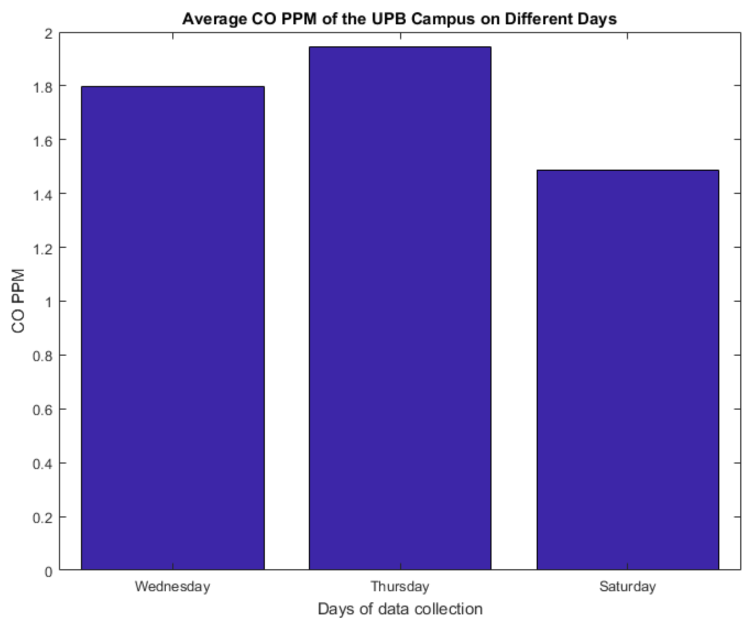


Figure 4.21: Bar graph of the average of all CO PPM data collected on a certain day compared to other days.

Just from observation, we can see that for both the CO and CO_2 PPM, weekdays have a higher PPM count compared to the weekends. This coincides with the working days of the campus. In weekdays, there are more vehicles and students in the campus compared to the weekends where there are less or even an absence of cars and students. This implies that there more sources of carbon emissions in the weekdays compared to the weekends. This is consistent for both of the gases.

We can also see that in Wednesdays, there is a slight drop in the CO and CO_2

PPM. This can be attributed as an effect of Car-less Wednesdays since there are less contributors to carbon emissions in the campus compared to normal weekdays but we cannot be sure that this is consistent for all the days in the weekdays since we have only values of Thursday to compare it to.

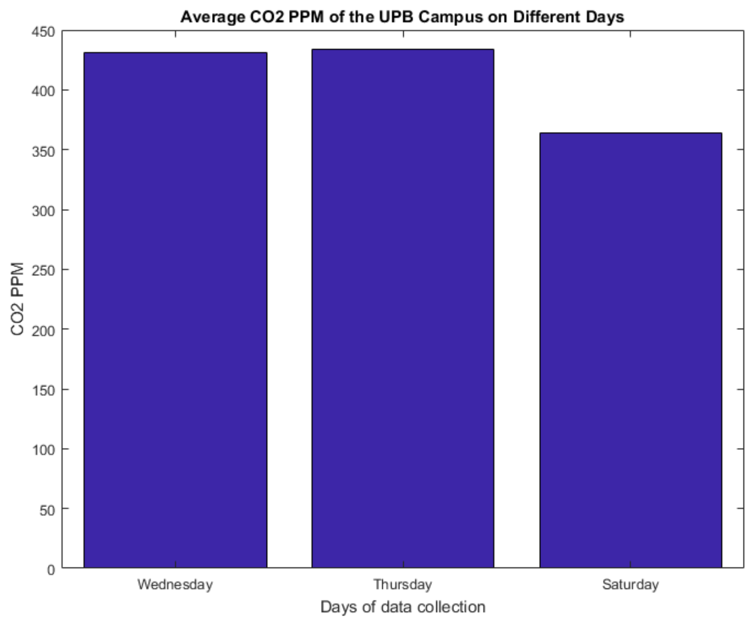


Figure 4.22: Bar graph of the average of all CO_2 PPM data collected on a certain day compared to other days.

4.2.3 Comparison between Times of the Day per Node

CO

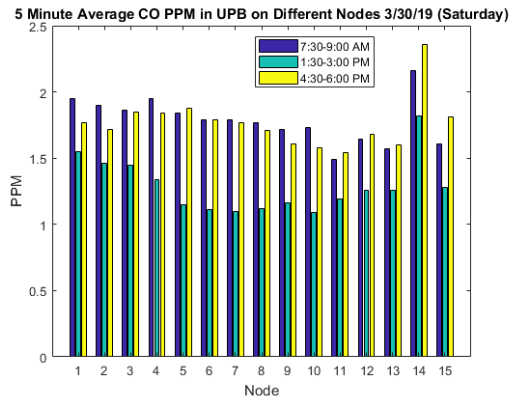


Figure 4.23: Comparison between the five minute CO PPM from different days (Morning peak time slot)

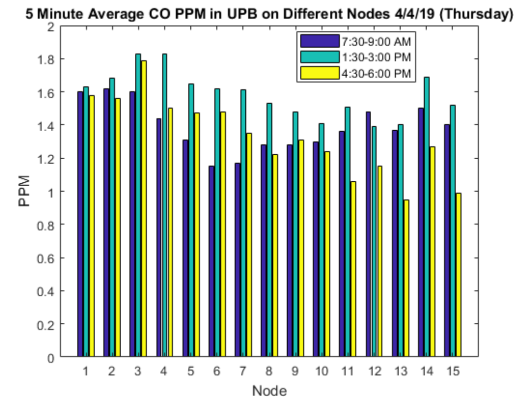


Figure 4.24: Comparison between the five minute CO PPM from different days (Afternoon peak time slot)

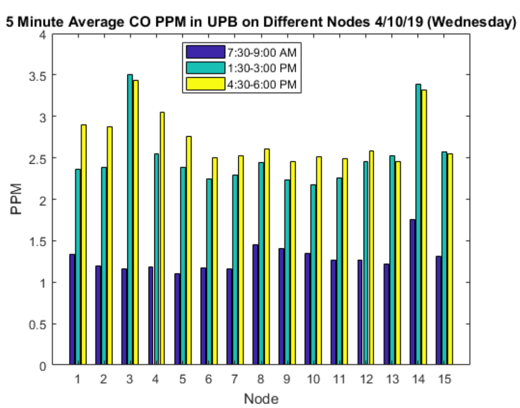


Figure 4.25: Comparison between the five minute CO PPM from different days (Off peak time slot)

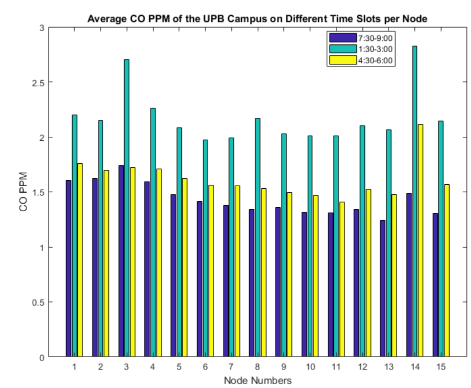


Figure 4.26: Bar graph of the average of all CO PPM data collected at each node on a certain time range compared to other time slots.

In the graph for the CO, we can see that node 14 still gave the highest PPM for the majority of the time slots. This is just further validation that this node is worth attention. We can also see that there is CO build up in nodes that are poorly ventilated like nodes 3 (Chemical Laboratory) and 8 (Canteen). These levels are still safe but we can see an increase on the Carbon Monoxide when it is 1:30-3:00 PM. Note that these values do not coincide with the Particulate Matter data from the study of Cassidy et.al[4]. This is to be expected since the pollutant that is a subproduct of emissions that emit CO is $PM_{2.5}$[24] not PM_{10} which was the focus of the study of Cassidy et.al.

CO_2

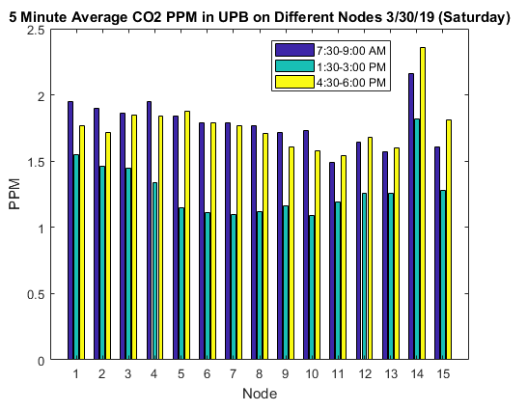


Figure 4.27: Comparison between the five minute CO_2 PPM from different days (Morning peak time slot)

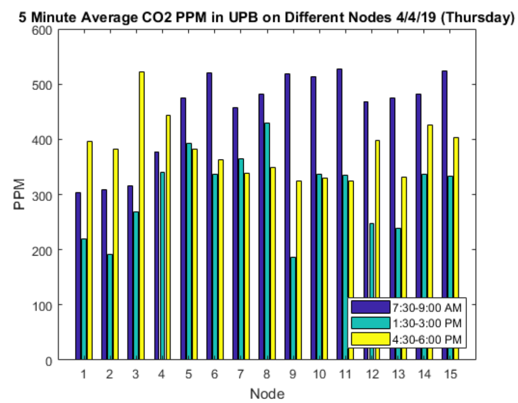


Figure 4.28: Comparison between the five minute CO_2 PPM from different days (Afternoon peak time slot)

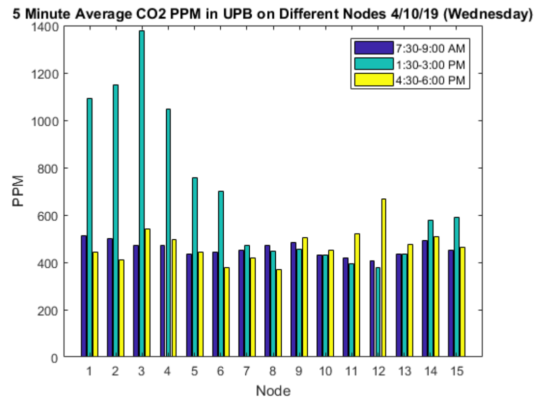


Figure 4.29: Comparison between the five minute CO_2 PPM from different days (Off peak time Slot)

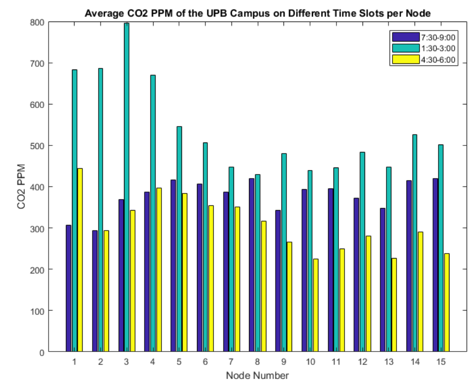


Figure 4.30: Bar graph of the average of all CO_2 PPM data collected at each node on a certain time range compared to other time slots.

For the CO_2 graph, we see a drastic increase in nodes 1-4 when it is 1:30-3:00 PM. For node 3 we can attribute this to the chemicals being used in the laboratory. For nodes 1,2, and 4; we can blame this on the nodes being near vehicles (Nodes 1 and 2 are roadside and node 4 is the UPB parking lot). The values decreases in node 5 where this node is somewhat far from the vehicles in parking lot. If we neglect the high values in the first 4 nodes, we still have a high value in node 14 at 7:30-9:00 AM and 1:30-3:00 PM. Note that these two time slots are when vehicle traffic is high at those nodes. The vehicle traffic decreases when it in the afternoon as compared to when it is morning and early afternoon.

If we were to compare the consistencies of both of the graphs, we can see that the results for the CO are more consistent compared to the CO_2 since there are no sudden spikes in the values that go on for sometime but eventually subside. This inconsistency in the CO_2 values can be attributed to the sensor's capability to detect numerous gases other than Carbon Dioxide. It can be possible that those areas have a certain concentrations of other gases that overpower the CO_2 which explains the spikes at those locations which are not considered high CO_2 concentration areas in the past results.

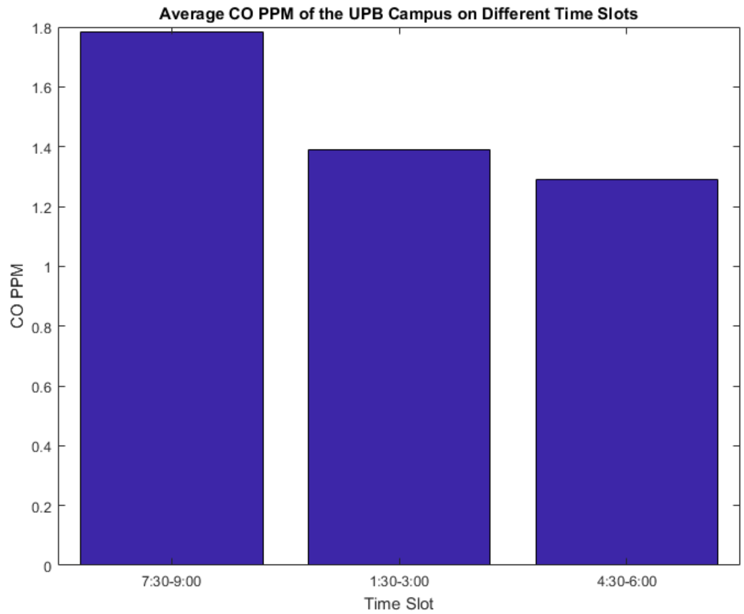


Figure 4.31: Bar graph of the average of all CO PPM data collected on a certain time range compared to other time slots.

For the comparison of the different time slots, we see time slots with contradicting highest and lowest values of PPM. To explain this, we can try to identify the main sources of these particular gases.

At 7:30-9:00 AM, the population of the UPB campus is less, compared to when it is noon and even in afternoon. This is different when it comes to vehicles though. In the morning, there is high traffic of public utility vehicles (taxis and jeepneys) that high school and college students use as their main mode of transport since it is cheaper and more convenient as Public Utility Jeepneys are numerous and are often have routes passing major schools. UPB does not have a defined assembly time. This means that only students that have 7:30 AM classes will have to go to the campus. Students also avoid these classes since it is too early and daytime sleepiness is prevalent in college students[18]. This also explains the low CO_2 PPM value since a human CO_2 emissions contribute to the ambient CO_2 PPM. Population in the campus is at its highest around noon and in the afternoon as majority of student enroll in classes late morning, noon, early afternoon to late afternoon.

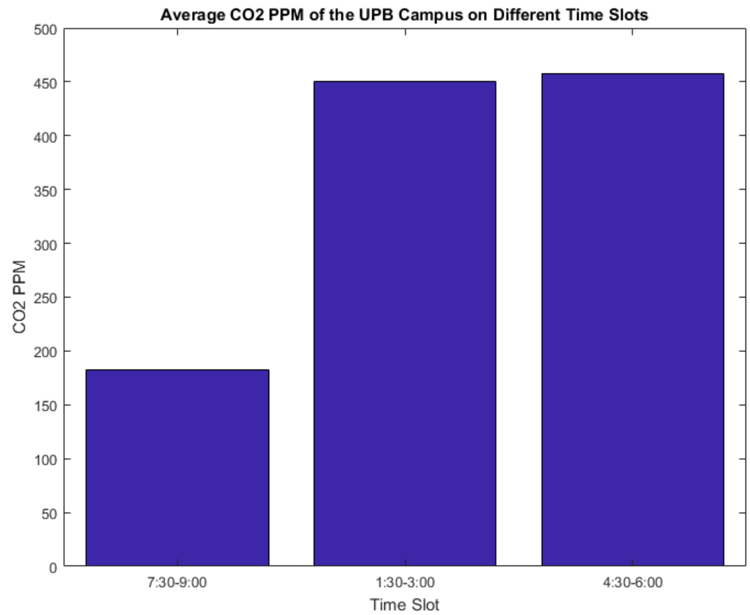


Figure 4.32: Bar graph of the average of all CO_2 PPM data collected on a certain time range compared to other time slots.

4.3 Twenty-four Hour Continuous CO and CO_2 PPM Data in UP Baguio

The Arduino sensor was placed from Wednesday(5/8/19) to Sunday(5/12/19) just outside the *COMSCI Lab 1* located at IB Building. This location was selected due to the ease of access of the power source from the *COMSCI Lab 1*.

4.3.1 Wednesday Twenty-four Hour Data

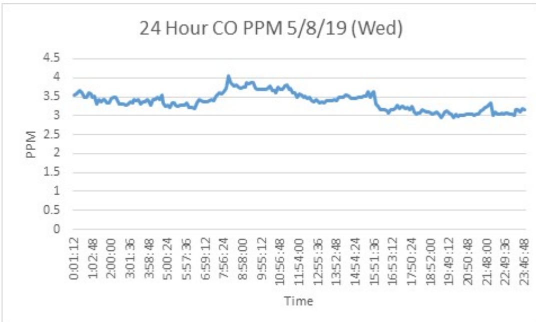


Figure 4.33: Twenty-four Hour CO PPM Data in UP Baguio on Wednesday

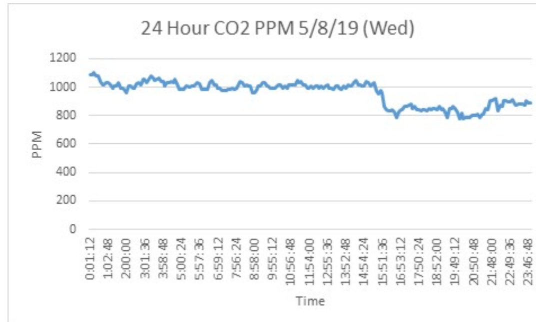


Figure 4.34: Twenty-four Hour CO_2 PPM Data in UP Baguio on Wednesday

The twenty-four hour Carbon Monoxide gas concentration data on Wednesday shown on figure 4.33, indicates a peak (about 4 PPM) in Carbon Monoxide gas concentration level on the morning peak time slot from 7:30-9:00 AM. A sudden decline happened about the off peak time slot from 1:30-3:00 PM which has a concentration of about 3 PPM. This coincides with the non-continuous data of the respective days of the week and times of the day.

On the right side, figure 4.34 shows the twenty-four hour continuous Carbon Dioxide gas concentration data on Wednesday. The CO_2 concentration remained on the 900-1000 PPM range from 12 AM up to the off peak time slot (1:30-3:00 PM).

4.3.2 Thursday Twenty-four Hour Data

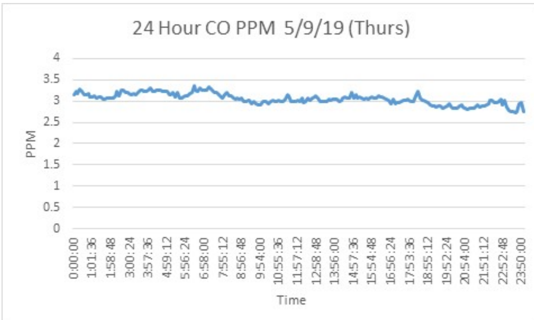


Figure 4.35: Twenty-four Hour CO PPM in UP Baguio on Thursday

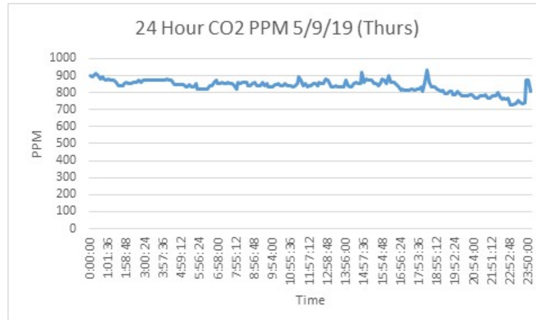


Figure 4.36: Twenty-four Hour CO_2 PPM in UP Baguio on Thursday

The twenty-four hour Carbon Monoxide gas concentration data on Thursday is shown on figure 4.35. It indicates a peak (about 3.5 PPM) in Carbon Monoxide gas concentration level on the early morning peak time slot from 6:00-7:30 AM. A slight decline happened about the after the morning peak time slot from 9:00-10:30 PM which has a concentration of about 3 PPM. This also coincides with the non-continuous data of the respective days of the week and times of the day.

On the right side, figure 4.36 shows the twenty-four hour continuous Carbon Dioxide gas concentration data on Thursday. The CO_2 concentration remained on the 800-900 PPM range from 12 AM up to the evening peak time slot (6:00-7:30 PM). After the late afternoon peak time slot (6:00-7:30 PM), the range dropped to 700-800 PPM.

4.3.3 Friday Twenty-four Hour Data

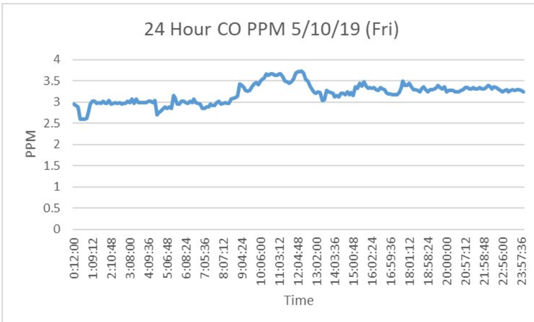


Figure 4.37: Twenty-four Hour CO PPM in UP Baguio on Friday

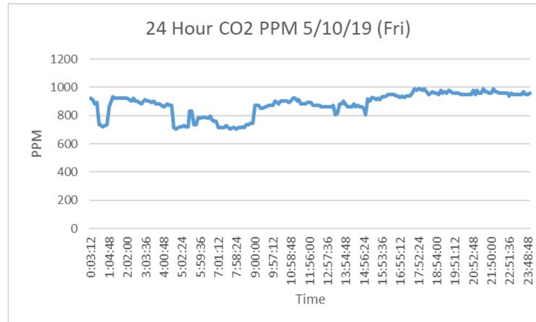


Figure 4.38: Twenty-four Hour CO_2 PPM in UP Baguio on Friday

The graph on figure 4.37 shows the twenty-four hour continuous Carbon Monoxide gas concentration data for Friday. The lower levels of about 2.5-3 PPM of Carbon Monoxide was observed until after the morning peak time slot (9:00-10:30 AM). This indicates that CO emission from the combinations of UP Drive, Gov. Pack road, and Harrison road accumulated on the parking lot. It may have also come from the vehicless parked on the lot. On about the off peak time slot (1:30-3:00 PM), the concentration lowered down to 3-3.5 PPM range.

On the right side, figure 4.38 shows the twenty-four hour continuous Carbon Dioxide gas concentration data for Friday. The CO_2 concentration on early morning (1:00-4:30 AM) shown a reaction from late Thursday evening concentration. The concentration lowered down during the early morning peak time slot (4:30 - 6:00 AM). It went back to about 850-900 PPM range after the morning peak hour(7:30-9:00 AM). The range becomes a little bit higher after the afternoon off peak time slot (1:30-3:00 PM).

4.3.4 Saturday Twenty-four Hour Data

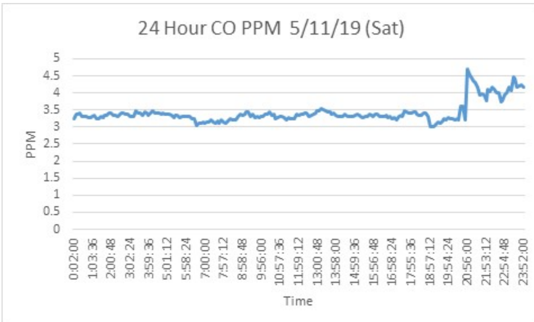


Figure 4.39: Twenty-four Hour *CO* PPM in UP Baguio on Saturday

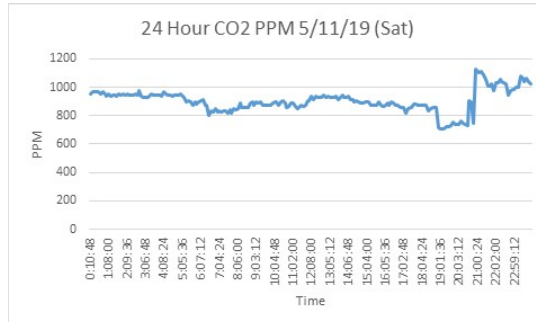


Figure 4.40: Twenty-four Hour CO_2 PPM in UP Baguio on Saturday

The graph on figure 4.39 shows the twenty-four hour continuous Carbon Monoxide gas concentration data for Friday. The concentration of Carbon Monoxide on Saturday is steady during the day ranging from 3-3.5 PPM. A peak of about 4.7 PPM was observed during the evening (8:00-9:30 PM).

On the right side, figure 4.40 shows the twenty-four hour continuous Carbon Dioxide gas concentration data for Friday. The CO_2 concentration on early morning (1:00-4:30 AM) shown a reaction from late Thursday evening concentration. The concentration lowered down during the early morning peak time slot (4:30 - 6:00 AM). It went back to about 850-900 PPM range after the morning peak hour(7:30-9:00 AM). The range becomes a little bit higher after the afternoon off peak time slot (1:30-3:00 PM).

4.4 Results of Modified Target Set Selection on UP Baguio Gas Concentration Data

Table 4.1: Results of TSS and Greedy TSS Algorithm for *CO* concentration

Date	Time	TSS	Greedy TSS
3/30/19(Sat)	7:30-9:00 AM	8	1,4,6,10,12,14
3/30/19(Sat)	1:30-3:00 PM	None	1,14,3
3/30/19(Sat)	4:30-6:00 PM	8	1,3,8,10,12,14
4/4/19(Thurs)	7:30-9:00 AM	None	1,3,8,10,12,14
4/4/19(Thurs)	1:30-3:00 PM	None	None
4/4/19(Thurs)	4:30-6:00 PM	None	None
4/10/19(Wed)	7:30-9:00 AM	None	None
4/10/19(Wed)	1:30-3:00 PM	4,7,10,12,14	1,3,4,8,10,12,14
4/10/19(Wed)	4:30-6:00 PM	1,4,6,8,12,13	1,3,4,8,10,12,14

Table 4.1 contains the results the application of the modified target set selection algorithm on UP Baguio Carbon Monoxide gas concentration in different times and dates. The cardinality of the target set on each times and dates indicates how difficult the current air quality condition can be cleaned. The absence of a target set implies that the current air quality condition is already acceptable and there is no need for air filters at that time and day. A larger target set means that the air at the time and day may be dirtier or unsafe compared to others. The most common nodes included in the target set are nodes near roads and nodes that are in places that have poor ventilation. We can see that some of the nodes that have high PPM values in the individual discussion of the results do not show up in the target set (node 9, node 2, etc.). This means that the algorithm also considers if a node is harder to clean compared to others. What does 'harder to clean' mean? It means that this node is isolated, meaning it has few or even a single neighbor that can reach it (node 1 and 12).

Table 4.2: Results of TSS and Greedy TSS Algorithm for CO_2 concentration

Date	Time	TSS	Greedy TSS
3/30/19(Sat)	7:30-9:00 AM	None	1
3/30/19(Sat)	1:30-3:00 PM	None	1,14,3
3/30/19(Sat)	4:30-6:00 PM	None	1,3,5,12
4/4/19(Thurs)	7:30-9:00 AM	None	6,10,12,14
4/4/19(Thurs)	1:30-3:00 PM	None	8
4/4/19(Thurs)	4:30-6:00 PM	None	3,14
4/10/19(Wed)	7:30-9:00 AM	5	1,3,8,10,12,14
4/10/19(Wed)	1:30-3:00 PM	1,3,4	1,2,3,4,6,10,14
4/10/19(Wed)	4:30-6:00 PM	12	1,3,10,12,14

In both results of the TSS algorithm, we get Wednesday as the day when air filters are needed for both CO and CO_2. More filters are needed to stabilize the concentrations of the gases in the air in the afternoon and evening compared to when it is morning. Note that, these time slots are when the numbers of students in the campus are its highest.

When comparing the two algorithms, the Greedy TSS algorithm always gave a higher amount of nodes compared to the TSS algorithm. This is the same as the source paper[8].

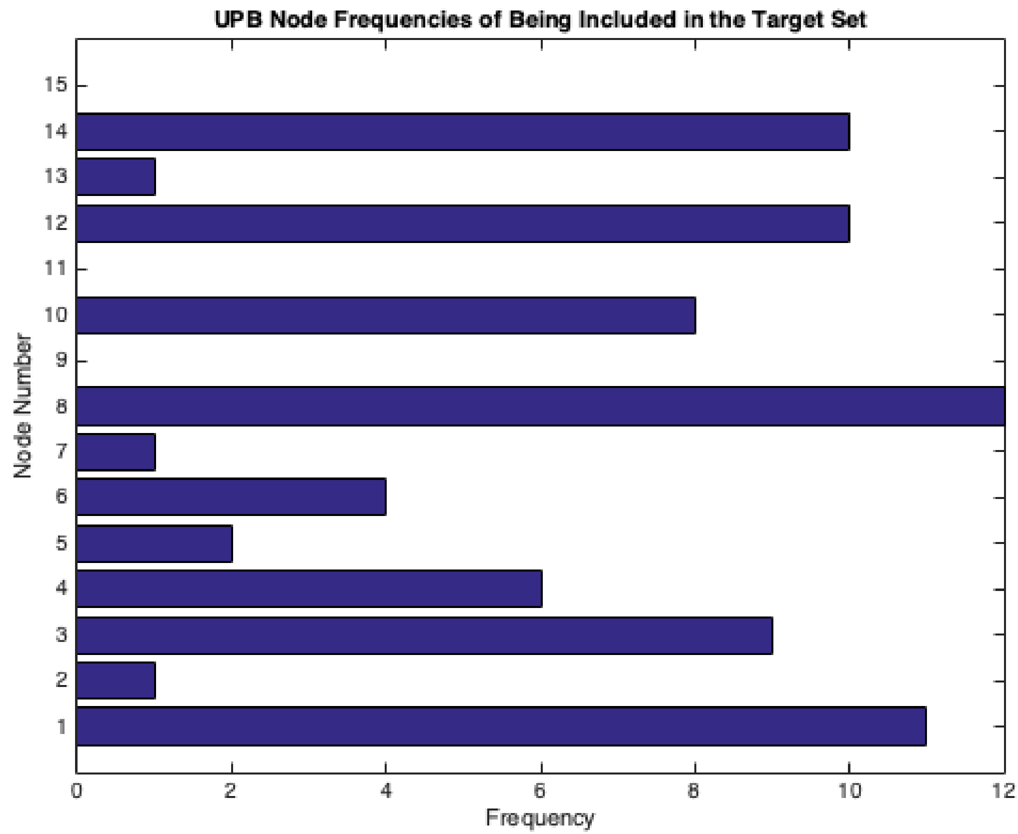


Figure 4.41: Frequencies of Node which was selected as Target Set in both Greedy and Non-greedy version on UP Baguio Gas Concentration Data

Nodes 1,8,12 and 14 have the highest frequencies as results of both algorithms for CO and CO_2. It is worth noting that nodes 1,12 and 14 are nodes beside roads. These roadside nodes have notably high Carbon Oxide concentrations compared to nodes inside the campus. This can also mean that the algorithms we used for obtaining the Target Sets for each time slot gives us nodes that will have the strongest effects to the health and well-being of the students in the campus.

We can also see that there are other nodes with high frequencies which are nodes 3, 10 and 8. These nodes are located indoors. These nodes have less air flow and ventilation compared to the the other nodes. The nodes with the highest frequencies are not nodes that have a higher amount of neighbors. This just means that the PPM values of the nodes have a bigger effect on it being picked by the algorithm compared to that node being picked for it's high degree.

Chapter 5

Conclusion and Recommendation

In this study, we discussed some of the factors that affect the CO and CO_2 concentrations. This includes the day of the week, time of the day, and the locations.

Considering the errors, the behavior of the days of the week coincides with the expected behavior. Car-less Wednesdays have lower CO concentrations at certain times. Thursday, a workday, reflects the high CO and CO_2 concentrations and Saturday shows the campus' low CO and CO_2 concentration due to a non-working day.

The times of the day: the peak and off peak hours have direct relations to CO and CO_2 concentrations. Morning peak time slot(7:30-9:00 AM) and afternoon peak time slot(4:30-6:00 PM) gave higher CO and CO_2 concentrations than the off peak time slot (1:30-3:00 PM). The time observations are further supported by the twenty-four hour concentration data of CO and CO_2.

The data collection locations pointed out the possible sources and accumulation of CO and CO_2 throughout the day and week. For the nodes to be selected as places to put filters in, it is best to pick nodes that near main sources of these pollutants, i.e roads and poorly ventilated areas.

There are many things to improve upon in our setup. To have get accurate values in the Carbon Oxide values, we recommend using industrial detectors that are pre-calibrated by manufacturers rather than the inexpensive sensors we have used in the study. We also recommend to consider to gather long term data to further confirm the results in this study. PM_{10} and $PM_{2.5}$ can also be considered as the thresholds for the nodes instead of the Carbon Oxides we used in the study.

The algorithm proposed in this study can also be improved upon. Wind-speed, distance, and other relevant variables can be added to have a more accurate and realistic locations for the target set. Also, adding more nodes to the graph can help get a more defined answer on where the filters should be.

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Appendix A

Table of the average CO and CO_2 of UPB

Figure A.1: Saturday CO Data (in PPM) 03-30-2019

Node	**7:30-9:00**	**1:30-3:00**	**4:30-6:30**
1	1.95	1.55	1.77
2	1.9	1.46	1.72
3	1.86	1.45	1.85
4	1.95	1.34	1.84
5	1.84	1.15	1.88
6	1.79	1.11	1.79
7	1.79	1.1	1.77
8	1.77	1.12	1.71
9	1.72	1.16	1.61
10	1.73	1.09	1.58
11	1.49	1.19	1.54
12	1.64	1.26	1.68
13	1.57	1.26	1.6
14	2.16	1.82	2.36
15	1.61	1.28	1.81

Figure A.2: Saturday CO2 Data (in PPM) 03-30-2019

Node	**7:30-9:00**	**1:30-3:00**	**4:30-6:30**
1	480.76	398.09	453.65
2	244.77	208.69	425.7
3	180.51	337.95	509.91
4	163.03	474.19	555.38
5	132.27	440.36	580.58
6	131.17	365.09	566.63
7	125.68	330.47	595.92
8	117.09	343.62	488.78
9	117.85	203.37	478.49
10	121.11	161.69	392.5
11	181.13	199.65	368.87
12	173.06	263.26	403.09
13	158.24	237.37	286.27
14	232.95	329.05	309.02
15	184.86	238.52	290.78

Figure A.3: Friday CO Data (in PPM) 04-04-2019

Node	**7:30-9:00**	**1:30-3:00**	**4:30-6:30**
1	1.6	1.63	1.58
2	1.62	1.68	1.56
3	1.6	1.83	1.79
4	1.44	1.83	1.5
5	1.31	1.65	1.47
6	1.15	1.62	1.48
7	1.17	1.61	1.35
8	1.28	1.53	1.22
9	1.28	1.48	1.31
10	1.3	1.41	1.24
11	1.36	1.51	1.06
12	1.48	1.39	1.15
13	1.37	1.4	0.95
14	1.5	1.69	1.27
15	1.4	1.52	0.99

Figure A.4: Friday CO2 Data (in PPM) 04-04-2019

Node	**7:30-9:00**	**1:30-3:00**	**4:30-6:30**
1	303.35	219.18	396.97
2	307.99	191.12	381.38
3	315.81	269.05	521.43
4	377.75	339.9	444.03
5	475.36	392.61	382.4
6	520.36	336.28	362.34
7	456.94	364.21	339.26
8	482.53	429.21	349.11
9	518.81	186.86	323.64
10	513.99	336.25	330.13
11	527.34	334.19	324.18
12	468.79	247.68	398.19
13	474.71	238.37	331.64
14	482.62	336.44	425.23
15	523.95	333.45	403.36

Figure A.5: Wednesday CO Data (in PPM) 04-10-2019

Node	**7:30-9:00**	**1:30-3:00**	**4:30-6:30**
1	1.34	2.36	2.9
2	1.2	2.38	2.87
3	1.16	3.51	3.43
4	1.18	2.55	3.05
5	1.1	2.39	2.76
6	1.17	2.25	2.5
7	1.16	2.29	2.53
8	1.45	2.44	2.61
9	1.4	2.23	2.46
10	1.35	2.17	2.51
11	1.27	2.26	2.49
12	1.27	2.45	2.58
13	1.22	2.52	2.46
14	1.76	3.39	3.32
15	1.31	2.57	2.55

Figure A.6: Wednesday CO2 Data (in PPM) 04-10-2019

Node	**7:30-9:00**	**1:30-3:00**	**4:30-6:30**
1	512.79	1092.31	443
2	499.28	1150.87	410.27
3	469.89	1377.47	541.57
4	469.55	1047.01	494.25
5	433.7	756.64	444.7
6	444.39	698.16	377.15
7	449.29	471.33	420.31
8	472.73	448.12	367.49
9	482.35	456.87	502.76
10	431.68	432.08	451.76
11	420.39	394.05	521.37
12	406.67	376.49	668.84
13	433.13	433.52	475.4
14	492.35	576.97	507.08
15	451.63	590.01	461.65