How to Optimize UBC's Fleet Management

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Climate change means that it will become more difficult to sustain our population at the current rate. Therefore scientists and environmentalists have been advocating to try and reverse the effects of climate change or at the very least, reduce the rate at which change is occurring. One of the ways to reduce the effects of climate change is to reduce the amount of carbon that is being produced overall. One method of doing that is called "carbon neutrality". Carbon neutrality is when the amount of carbon that is being released into the Earth's atmosphere by a company/organization is also the amount that is being removing from the atmosphere so that their net amount of carbon emission is zero. Even better than that is "carbon positivity," this is when the net amount of carbon emissions a company/organization is producing is less than zero. Companies and organizations are being incentivized to reduce their emissions through the enactment of certain carbon laws. The provincial government of British Columbia has implemented a provincial tax which states that companies and organizations will have to pay between \$40 to \$45 per ton of carbon dioxide that they produce. This number will only increase as time goes on. For the University of British Columbia (UBC) alone, this will mean that financial costs to run the university could increase by over \$5,000,000 by 2040 ("UBC Vancouver Climate Action Plan 2030."). Therefore it is imperative that action to reduce carbon should be taken.

UBC declared a climate emergency in December 2019 ("UBC Vancouver Climate Action Plan 2030."). As a result they created the "Climate Action Plan 2030" (CAP 2030) that will help to reduce carbon emission ("UBC Vancouver Climate Action Plan 2030."). UBC is hoping that CAP 2030 will allow UBC to "accelerate the pathway to becoming net zero through clean energy solutions and energy-efficient technologies, as well as identifying new ways to reduce emissions in areas that every university community member has influence over, including commuting, food, waste, and business air travel." ("UBC Vancouver Climate Action Plan 2030.") In other words, CAP 2030 will allow UBC to optimize (in this case minimizing) the amount of carbon that is being produced through aspects that everyone on campus can contribute to, not just university operations. Five areas have been identified to help reduce emissions. The first is to reduce emission from existing buildings which is currently where most of the emissions come from. Second is to figure out how new buildings will get energy and deal with their emissions. Third is the behavioral change of people on campus to reduce emissions. Fourth is to deal with how energy is supplied to campus. And finally the fifth area is reducing emissions from vehicles such as departmental vehicles and operational vehicles.

The aim of this project is to show that UBC can minimize their carbon emissions in the form of a linear programming problem. When looking at this problem as a linear problem, we will consider only the fifth category identified in CAP 2030 – UBC's fleet size and reducing emission from vehicles. Although, the vehicles are the smallest component of the total emissions produced in campus (0.7% of total emissons), I have chosen this aspect because the vehicles are visible and can be used as a constant reminder to all that reducing our personal carbon footprint is important. We will also consider the financial aspect of reducing emissions.

In the fleet there are three types of vehicles. The light duty vehicles (l), the light duty trucks (m) and heavy duty vehicles (h). In each type there are different types of fuels, these include electric vehicles (EV), "Plug in" electric vehicles (PHEV), hybrid vehicles (HEV), hydrogen fuel cell vehicles (HFCV), natural gas/propane (NGP), and finally gas/diesel (GD). Since some fuel types are not available for certain vehicle types (e.g. electric is not available for trucks) I will put the fuel types into three different categories; electric (e) which includes EV, PHEV, and HEV, hydrogen fuel cell (f) which includes HFCV, and gas (g) which includes NGP and GD. The number of vehicles in UBC's fleet is then

$$l_e + l_f + l_g + m_f + m_g + h_f + h_g$$

Now the gas vehicles have to be replaced so emissions can be minimized with the following 3 conditions

1. The new fleet size cannot be smaller than the old fleet size
2. There is only a certain amount of money allocated each year to replace the cars
3. The cost of running the fleet cannot go up

Our objective function is to minimize the emissions that the fleet produces by replacing the highest emission vehicles in each class.

The first step in solving our linear programming problem is to determine the mathematical equations of our problem. Let us allow our variables to represent the number of vehicles that each specific category has. For the sake of simplicity we will group the vehicles by type and not fuel type, thus we have the following three variables l, m, h. These are all the vehicles with gas fuel. Since we are trying to replace high emission vehicles to minimize the emissions produced we will also have the variables l_n, m_n, h_n. These three new variables will represent the number of low emission vehicles that the fleet has (i.e. the vehicles that have been replaced). Since both light duty trucks (m) and heavy duty trucks (h) only have gas and hydrogen fuel cell fuels available, we know that if we replace those trucks we are replacing gas vehicles with hydrogen fuel cell vehicles. Therefore our objective function will be

$$c_1 l + c_2 m + c_3 h + c_4 l_n + c_5 m_n + c_6 h_n$$

Where $\vec{c}$ represents the average emission of that type of vehicle. We know that the UBC fleet emissions from 2019 were 1093 tons of CO_2e ("2020 Climate Change Accountability Report."). We are using values from 2019 and not 2020 because 2020 was not indicative of normal fleet usage since UBC was working in an online teaching model. The average emission of a light duty car and light duty trucks is around 4 g/mi ("Light Duty Vehicle Emissions."). The average emissions of a heavy duty truck is 12 g/mi ("CO2 Emissions from Heavy-Duty Vehicles."). The coefficient constants of l_n, m_n, h_n will be 0 because hydrogen fuel cells do not produce any CO_2.

Therefore our updated objective function will look like

$$4l + 4m + 12h + 0l_n + 0m_n + 0h_n$$

It must be stated that although the amount of emissions is the same for the light duty cars and trucks we have not grouped them together because these vehicles perform different functions and cannot be interchangeably used.

In the conditions mentioned above we stated that, "There is only a certain amount of money allocated each year to replace the cars". Thus we fashion this constraint as follows

$$r_1\left(l-l_n\right)+r_2\left(m-m_n\right)+r_3\left(h-h_n\right)\leq b_2$$
$$r_1l+r_2m+r_3h-r_1l_n-r_2m_n-r_3h_n\leq b_2$$

In the constraint above $\vec{r}$ represents the amount of money it takes to replace the vehicle, in other words it is the average cost of a new vehicle of the new fuel type, and b_2 represents the allocated amount of money given to optimize the fleet.

We can estimate the values of $\vec{r}$ by researching the price of these new vehicles. For light duty cars since we know that gas vehicles can we replaced by either hydrogen fuel cell or electric cars, so we will take the average price of the two. A Toyota hydrogen fuel cells costs around \$50,000 ("2020 Toyota Mirai Prices, Reviews, and Pictures."). A Toyota electric car costs around \$33,000 ("Toyota Prius Prime."). So we will say that $r_1 = \$41,500$. The average prices of hydrogen cell trucks are hard to find so we will estimate them based on r_1 For light duty trucks the average price of a light duty truck is \$38000 ("Average New Light Truck Price."). So we will say that $r_2 = 45000$. For heavy duty vehicles a hydrogen fuel cell heavy duty truck costs around \$120,000 (ben@durabakcompany.com). So we will say that $r_3 = 120000$.

b_2 refers to the amount of money allocated by UBC to replacing vehicles in a given budget year. We do not know the budget that UBC has allocated to fleet optimization. However we do know that UBC received \$2,683,000,000 for the 2020/2021 school year ("UBC 2020/2021 BUDGET."). Considering thate climate change is a big issue to UBC let us assume that UBC will allocate 5% of this budget to solving the problem. Furthermore fleet emissions only account for 0.7% of total emissions, so we will assume that we have 0.7% of the climate change budget. This gives us a budget of \$9,390,500, which is what we will assign to b_2

Our updated constraint then looks like

$$41500l + 45000m + 120000h - 41500l_n - 45000m_n - 120000h_n \leq 9390500$$

For the third constraint we say that, "The cost of running the fleet cannot go up". We can separate this into two constraints – the cost of fuel and the cost of running the fleet. The first is that the cost of fuel should not go up. Thus we get constraints that looks like the following

$$q_1 l + q_2 m + q_3 h + q_4 l_n + q_5 m_n + q_6 h_n \leq b_3$$

$$s_1 l + s_2 m + s_3 h + s_4 l_n + s_5 m_n + s_6 h_n \leq b_4$$

Where $\vec{q}$ refers to the cost of fuel per year for the corresponding vehicles and b_3 indicates the current fuel costs per year for running the fleet. $\vec{s}$ refers to the maintenance costs and b_4 indicates current maintenance costs.

UBC's budget for fuel is not available so we will average it on the average cost of running a fleet. Assuming it takes around \$8000 a year to run one truck (Sickels). We have a current fleet of 435 but we will account for a fleet size of 480 because we know that we will be increasing our fleet size and we want to have a little extra money. So our average fleet price would be \$3,840,000. In addition to that we will allocate 55% of that to fuel costs. We separated this budget in approximately half because we know that fuel is one of the largest repetitive costs for owning a vehicle. This give us $b_3 = 2112000$ and $b_4 = 1728000$

The average cost of fuel for a light duty car is around \$1500 ("2019 FUEL CONSUMPTION GUIDE."). The average cost of fuel for a light duty truck is is around \$2000 ("2019 FUEL CONSUMPTION GUIDE."). The average cost of a heavy duty vehicle is around \$3000 (Sickels). The average cost of a electric/hydrogen fuel cell light duty car and truck is around \$400 ("2019 FUEL CONSUMPTION GUIDE.").The price for the heavy duty hydrogen fuel cell trucks is not readily available therefore we will use a similar ratio to the normal fuel vehicles. The price of fuel for the heavy duty vehicle will be around \$600.

So our updated constraint looks like

$$1500l + 2000m + 3000h + 400l_n + 400m_n + 600h_n \leq 2112000$$

The next constraint comes from the other costs of running a fleet per year (maintenance checks, cost of new electric stations, etc...). The cost of maintaining light duty vehicles is around \$1200 and for a electric/hydrogen light duty vehicle is \$900 (Preston). There is an additional \$700 cost for electric vehicles for charging stations and the likes ("Learn How Much It Costs to Install an Electric Vehicle Charging Station.").The cost of maintaining a heavy duty truck is \$15,000 ("The Cost of Trucking."). According to Green Car Congress owning a hydrogen cell heavy duty truck is less expensive than a gas truck so we will say that it costs around \$12,000 ("NREL Report Finds Electrified Heavy-Duty Vehicle Powertrains Could Provide Lower Total Cost of Ownership than Diesel under Certain Conditions."). So our next constraint will look like the following

$$1200l + 1200m + 15000h + 1600l_n + 900m_n + 12000h_n \leq 1728000$$

For our fourth through sixth constraints we will be determining how many vehicles can be in each category. For the first constraint that was specified above, "The new fleet size cannot be larger than the old fleet size". For our fourth constraint we do not want to exceed the number of light duty cars we currently have. So our constraint will look like the following

$$l + l_n \geq 62$$

For our fifth constraint we do not want to exceed the number of light duty trucks we currently have. So our constraint will look like the following

$$m + m_n \geq 296$$

For our sixth constraint we do not want to exceed the number of heavy duty trucks we currently have. So our constraint will look like the following

$$h + h_n \geq 77$$

The values for the fourth through sixth constraint were deduced from "2020 Climate Change Accountability Report."

We also have five additional constraints, these account for the current number of sustainable vehicles in the fleet. Without these constraints the optimal solution would just be to replace all gas vehicles with their sustainable counterpart, however while this is mathematically feasible it is not realistically feasible. The first three constraints will determine the minimum number of sustainable vehicles UBC already has in its current fleet ("2018 UBC Carbon Neutral Action Report.")

$$l_n \geq 30$$

$$m_n \geq 5$$

$$h_n \geq 5$$

We also know that UBC replaces or purchases about 8-9 vehicles per year, so we get the following constraint where we say that we can only have 10 new vehicles. We are assuming that since UBC is a climate conscious school, they will only purchase sustainable vehicles going forward. Thus

$$l_n + m_n + h_n \leq 51$$

Using all the constraints that we deduced above we can see that our Linear Problem will look like the following.

$$
\begin{aligned}
\min \quad & 4l + 4m + 12h + 0l_n + 0m_n + 0h_n \\
\text{s.t.} \quad & 41500l + 45000m + 120000h - 41500l_n - 45000m_n - 120000h_n \leq 9390500, \\
& 1500l + 2000m + 3000h + 400l_n + 400m_n + 600h_n \leq 2112000, \\
& 1200l + 1200m + 15000h + 1600l_n + 900m_n + 12000h_n \leq 1728000, \\
& l + l_n \geq 62, \\
& m + m_n \geq 296, \\
& h + h_n \geq 77, \\
& l_n \geq 30, \\
& m_n \geq 6, \\
& h_n \geq 5, \\
& l_n + m_n + h_n \leq 51, \\
& l, m, h, l_n, m_n, h_n \geq 0
\end{aligned}
$$

Then we convert it to standard form

$$
\begin{aligned}
\max \quad & -4l - 4m - 12h - 0l_n - 0m_n - 0h_n \\
\text{s.t.} \quad & 41500l + 45000m + 120000h - 41500l_n - 45000m_n - 120000h_n \leq 9390500, \\
& 1500l + 2000m + 3000h + 400l_n + 400m_n + 600h_n \leq 2112000, \\
& 1200l + 1200m + 15000h + 1600l_n + 900m_n + 12000h_n \leq 1728000, \\
& -l - l_n \leq -62, \\
& -m - m_n \leq -296, \\
& -h - h_n \leq -77, \\
& -l_n \leq -30, \\
& -m_n \leq -6, \\
& -h_n \leq -5, \\
& l_n + m_n + h_n \leq 51, \\
& l, m, h, l_n, m_n, h_n \geq 0
\end{aligned}
$$

I solved this problem by using Pulp, the code is below

```
import sys
!{sys.executable} -m pip install pulp
import pulp
import numpy as np

# Create a LP Maximization problem
Lp_prob = pulp.LpProblem('Vanderbei1.1', pulp.LpMinimize)  # Comments can also be added after a line of code.

# Create problem Decision Variables
l = pulp.LpVariable("l")
m = pulp.LpVariable("m")
h = pulp.LpVariable("h")
ln = pulp.LpVariable("ln")
mn = pulp.LpVariable("mn")
hn = pulp.LpVariable("hn")


# We put objective function first then constraints.

# Objective Function
Lp_prob += (4*l)+(4*m)+(12*h)+ (0*ln) + (0*mn)+ (0*hn)

# Constraints:
Lp_prob += (41500*l) + (45000* m) +(120000* h) - (45000*ln) - (38000*mn) - (120000*hn) <= 9390500
Lp_prob += (1500*l) + (2000* m) +(3000* h) + (400*ln) + (400*mn) + (600*hn) <= 2112000
Lp_prob += (1200*l) + (1200* m) +(15000* h) + (1600*ln) + (900*mn) + (12000*hn) <= 1728000
Lp_prob += l + ln >= 62
Lp_prob += m + mn >= 296
Lp_prob += h + hn >= 77
Lp_prob += ln + mn +hn <= 51
Lp_prob += ln>= 30
Lp_prob += mn>= 6
Lp_prob += hn>= 5
Lp_prob += l>= 0
Lp_prob += m>= 0
Lp_prob += h>= 0
Lp_prob += ln>= 0
Lp_prob += mn>= 0
Lp_prob += hn>= 0

print(Lp_prob)

Lp_prob.solve()

for variable in Lp_prob.variables():
        print(variable.name, "=", variable.varValue)
print("Optimal value is z = ", pulp.value(Lp_prob.objective))
```

Using this code we see that the optimal value for gas emissions is 2032 g/mi with an optimal solution of $h = 62, h_n = 15, l = 32, l_n = 30, m = 290, m_n = 6$. This answer makes sense because we know that the largest emitter is the heavy duty trucks, so replacing those first is most likely to make the biggest impact on the total emission.

Next we need to see if the above solution produced a reduction in emissions. However, the emissions given by the university are in tons and the emissions for each vehicle is in g/mi. So first we will find how many miles the fleet travelled in 2019 and then assume that the new fleet travels a similar amount to find the emissions in tons.

$$
\begin{aligned}
(32)4g/mi + (290)4g/mi + (72)12g/mi &= 1093ton \\
2152g/mi &= 1.093 \times 10^9 g \\
\text{miles travelled in 2019} &\approx 507900mi
\end{aligned}
$$

$$
\begin{aligned}
2032g/mi \times 507900mi &= 1032052800g \\
&= 1032.0528ton
\end{aligned}
$$

Thus we see that the yearly emissions of our optimized fleet is approximately 1032 tCO_2e. The optimized solution reduced emission only by 5.5%

This bring us to the shortcomings of this model. The biggest shortcoming of this model is the monetary budget that we used. Unfortunately UBC does not provide a detailed budget report for their fleet management. As a result the budget used in this paper was estimated on known budgets and worldwide fleet averages. This is inaccurate because UBC is a public institution, and may have certain supplier/government deals and receive vehicles and supplies at a lower cost. Similarly the fleet averages that I referenced were all for private companies who might have different costs than public institutions. Also the budget used for climate change was 5% of university budget, this is a very optimistic budget. A discussion with my father who works in the car industry indicated that companies do not spend more than 1% of their budget for climate related issues. Refining the cost and budget values will give a more realistic solution. I believe that the more realistic solution will still inform us to replace the heavy duty trucks first because targeting the higher emission vehicles makes more sense, however it might change the number of trucks that are being replaced at any given time. Another shortcoming is that the constraints on the vehicles are very simple. If we were to make this model more realistic we might have three separate linear programming problems for each vehicle type.

From this project it can be concluded that if UBC allocated 0.00035% of it budget to fleet replacement to reduce emissions, it would have to replace 10 heavy duty trucks. Then the amount of emissions for the fleet reduces by about approximately 5.5%. For a more impactful change, UBC would have to allocate more money to fleet management. An extension to this project would be to introduce time variables and determine the earliest time that the entire fleet could be replaced with a low emission climate friendly fleet.

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