Canada's transportation network

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Transportation is a core service to all countries around the world, each country with unique challenges. In this report we will analyze Canada's transportation network for the general public, comparing provincial and federal spending. Our goal is to present the reader with different modes of transport, comparing overall usage, government spending, revenue, efficiency. We found that Canada relies on cars and roads as it's primary mode of transportation and for most people it is the most efficient way to commute. Canada has a lot of opportunities for improvement in sustainable transportation - and we will explore such areas as growth opportunities for the country's transportation network.

Analysis

In our analysis, our team looked at Government spending and the usage rates of Canada's transportation network. We wanted to answer these high level questions:
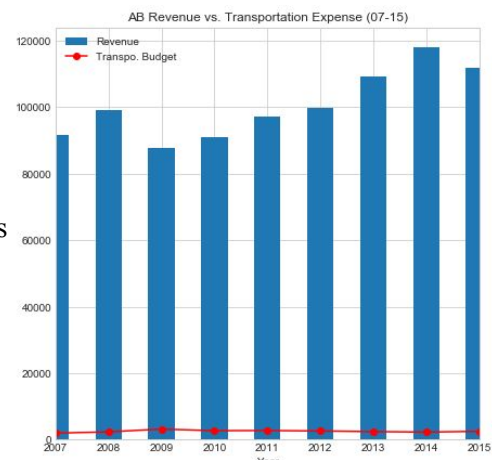
- **How much** do the federal and provincial governments spend on each mode of transportation?
- **Who** uses each mode of transportation?
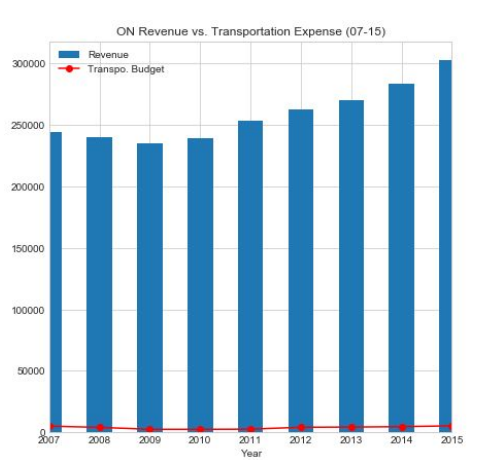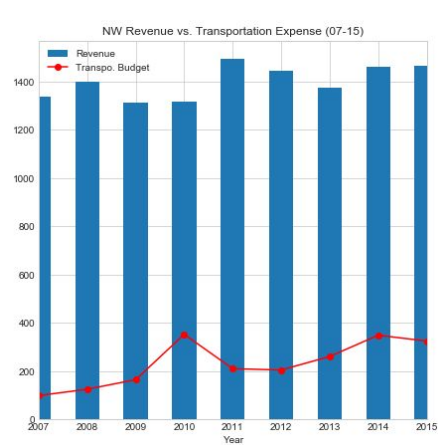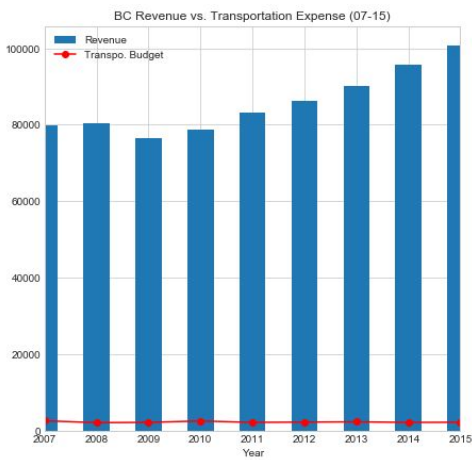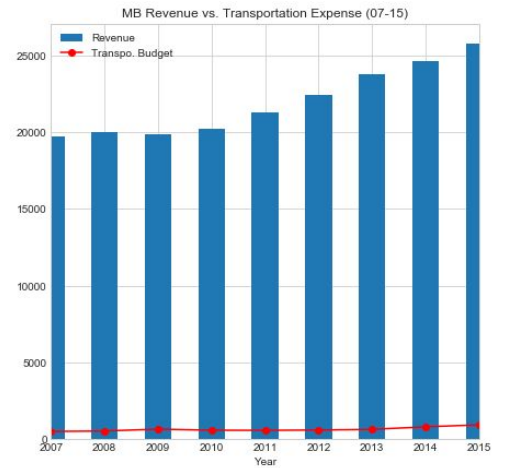- **How** efficient is each mode of transportation?

Each of these questions could be a report of their own, for example analysing how budgets change with populations, how they react during a recession, or budget changes in election years. Instead, we chose to take a holistic view of transportation to first get an idea of how different modes of transportation are being used, how much they cost, and identify what works well. To answer these questions, we sourced data at the provincial and federal levels, from Stats Canada, the 2016 Canadian Census, and more. Each of the datasets will be introduced as they are used in each section.
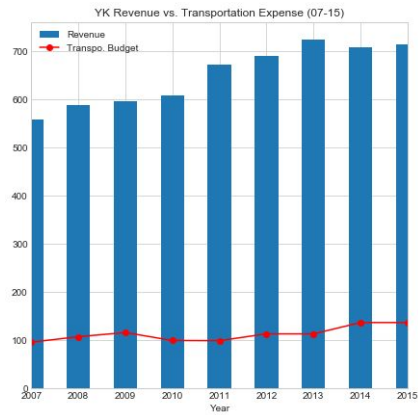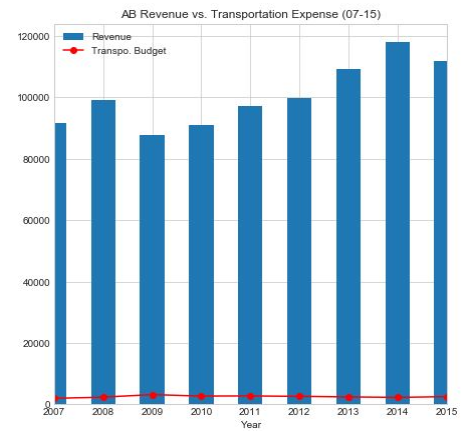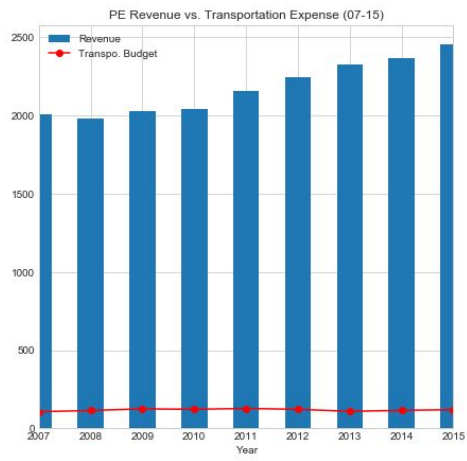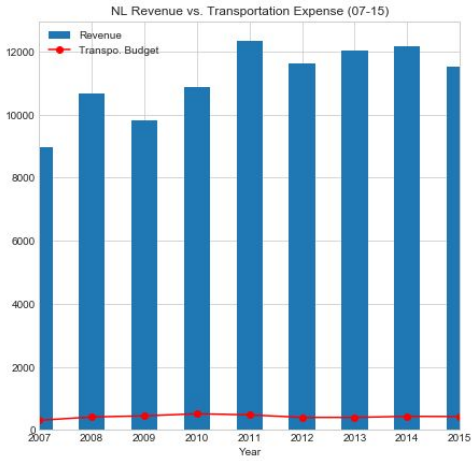
Transportation spending

We begin by looking at how much money is spent on transportation, and by whom. Understanding budgets means understanding which systems have the best cost efficiency and understanding the breakdown of expenditures by mode of transportations gives us clues into areas for improvement.

Transportation expenditures and provincial revenues were compared to see whether the expenses on transportation are affected by the revenue a province generates. Dataset [1] - *Transportation expenditures, population and per capita transportation expenditure* was used for the below graphs. Datasets were first cleaned by dropping null values and subsets for each province were created for comparison. Below are comparisons per province:

NL Revenue vs. Transportation Expense (07-15)

PE Revenue vs. Transportation Expense (07-15)

AB Revenue vs. Transportation Expense (07-15)

YK Revenue vs. Transportation Expense (07-15)

NB Revenue vs. Transportation Expense (07-15)

MB Revenue vs. Transportation Expense (07-15)

BC Revenue vs. Transportation Expense (07-15)

NW Revenue vs. Transportation Expense (07-15)

ON Revenue vs. Transportation Expense (07-15)

It looks like provincial revenues do not affect the transportation budget for our provinces and territories. Although Ontario generates the most revenue, its transportation budget was not significantly higher than other provinces'. This is due to the Ontario government is still targeting on relieving the commute struggling in the GTA area first, and has promised more funds for more frequent public transportation and subway extension (see [12]) The rest of the cities in Ontario still rely on cars as the most convenient means of transportation, while there is room for improvement for their public transportation systems.

Effects of population on public transportation usage and per capita transportation expenditure

Public transportation is an essential mode of transportation for many everyday commuters. It's very hard to imagine large North American cities without an implementation of public transportation (subways, buses, streetcars, etc.). While we can easily envision vast suburban areas with only basic public transportation systems with long wait times, rural areas don't seem to have modes of public transportation

at all. Intuitively, we can see that denser and more populated areas with higher traffic would benefit from more sophisticated transit systems, but when can we decide that a population is high enough to ensure the highest usage of a public transportation system, while maintaining low costs? Herein, we hypothesize that a higher population leads to a greater percentage of the population using public transportation systems and lower costs of implementing one. To approach the problem, we have used two open source data sets from stats Canada that have records of the provincial/territorial per capita transportation expenditure and another dataset of commuters and the modes of transportation that they use.[1,3]

To answer our hypothesis, we first needed to prepare the datasets for analysis. Luckily, the websites that the data was procured from had options to summarize the data for each province/territory. This option eliminated many of the difficulties of handling the jargon and nomenclature that was used for the raw data, and the data set that was downloaded was simple without any missing values. Very minimal cleaning was needed, and minimal coding was needed to combine the dataframes for analysis.
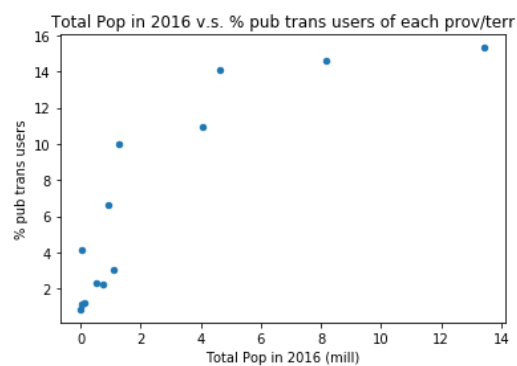
The initial relationship that was observed was the relationship between a province or territory's population to the percentage of that population that would use public transportation for their daily commute. What is observed is a clear trend, where increased populations increase to a greater percentage of population using public transportation (fig. 1). What's interesting is how the percentage of users tapers off very starkly from about 3-4 million people and on. What this tells us is that there seems to be an optimal population a province or territory needs to achieve to have optimal amounts of the population that'll make use of their public transportation systems. So, it appears that higher populations do indeed lead to a greater percentage of the population using public transportation, but there seems to be a limit to how many people use public transportation.
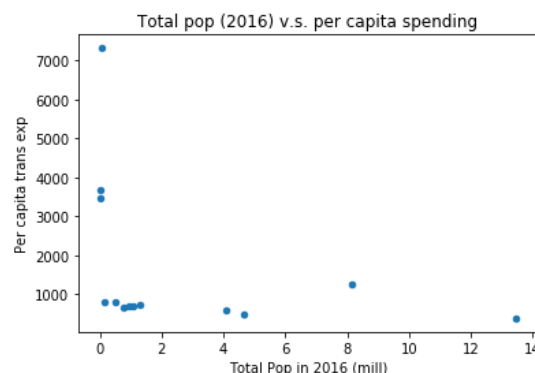
The second trend we set out to observe was the relationship between per capita transportation expenditure and the total population. The initial plot of all the provinces and territories showed three obvious outliers that corresponded to the three territories (fig. 2). Because no smooth trend was observed, it was assumed that there were other more important parameters inplay, other than the size of the population, that influenced the per capita transportation expenditure of the territories.

A closer look at just the provinces show another trend that is different from the logarithmic curving we see in analyzing the percentage of users and populations. When we omit the territories and plot the provinces alone, a new pattern emerges where there is a near linear relationship between the total population and the per capita expenditure (fig. 3). There is an outlier that shows incredibly high per capita expenditure even with a considerable population. This point represents Quebec. An article explains that a major issue is that Quebec's infrastructure is aging and the increasing usage of cars has caused more roads to be built and maintained.[4] Overall, this data supports our hypothesis that a greater population also increases the feasibility of a public transportation system. Though, these expenditure values do not reflect the cost of upkeeping a public transportation system

directly as the total transportation expenditure is not distributed the same across all provinces and territories. Hence, total transportation expenditure is not a direct reflection of how much is spent on public transportation systems.

Total pop (2016) v.s. per capita spending (adj)
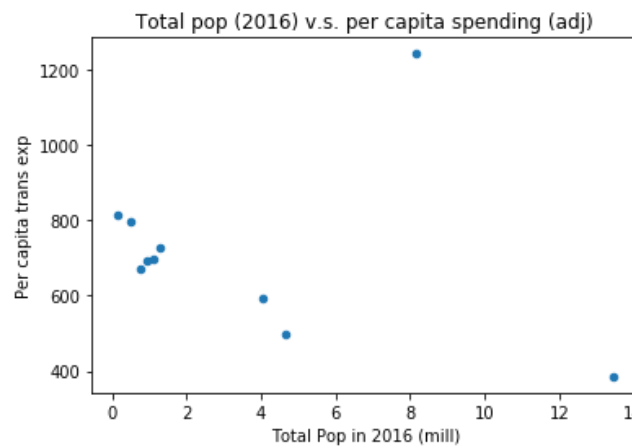
In conclusion, we have supported our hypothesis that the number of users of a public transportation system and overall cost of having a public transportation system is related to a population. Where higher costs lead to an increased percentage of users. During our study we found a very interesting trend where the percentage of users starts to cap off at a provincial/territorial population of 3-4 million people. An interesting future direction would be to investigate this phenomenon internationally and to see how different population groups respond to increasing populations and if there's a way to increase the percentage of public transit users. The per capita transportation expenditure against the total populations of provinces and territories showed a relatively intuitive trend. But a question arises from the outlier of figure 3, if Quebec has such high expenditures due to increased car usage, would the opposite be true if more commuters used public transportation instead?
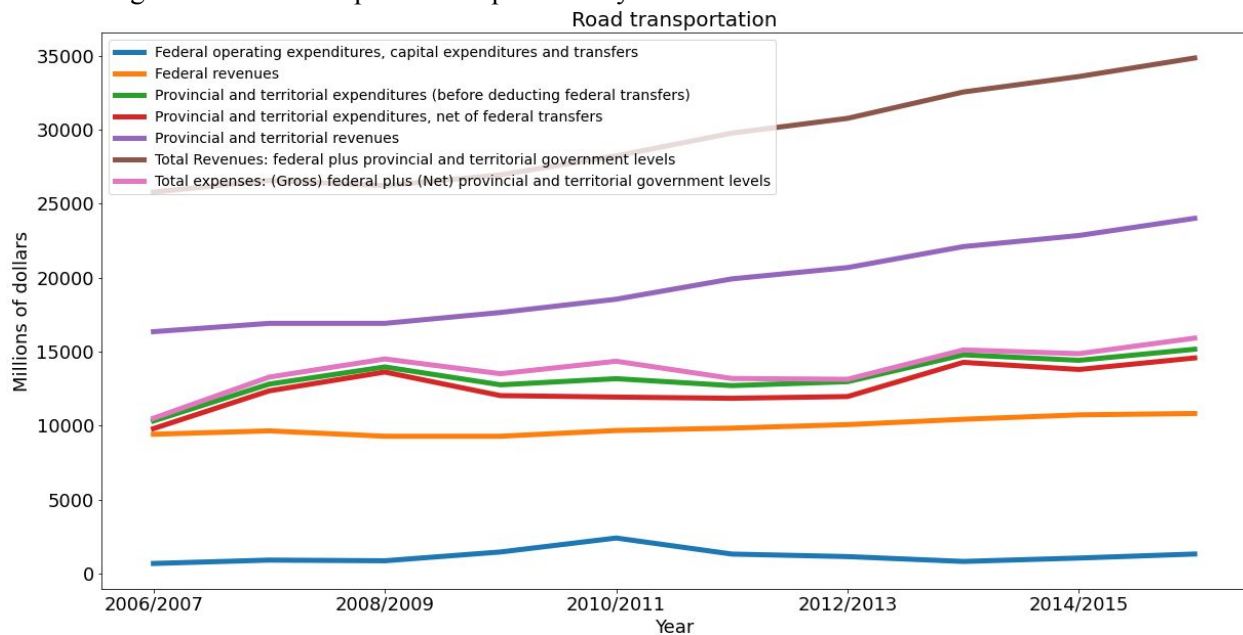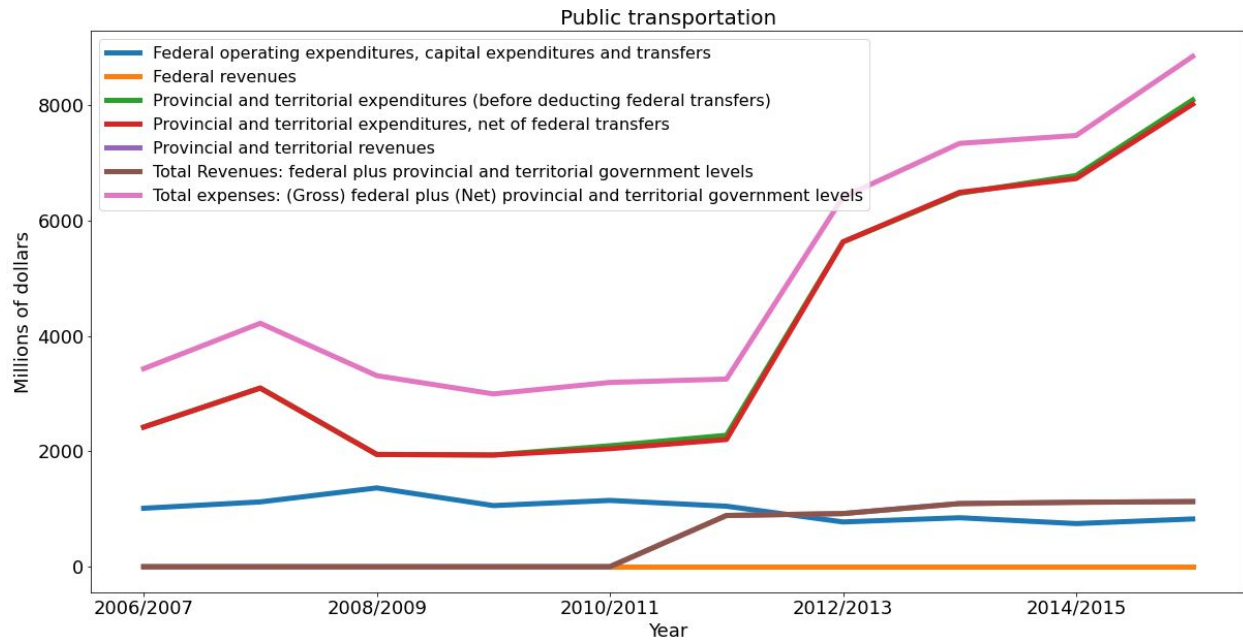
Transportation revenue

According to the Ministry of Transportation, the Government of Canada has an ambitious vision to make our transportation system safe, secure, more efficient and environmentally sustainable. Consistent with this, the Canadian government has destined very large sums of money to the transportation industry, in 2015, $30644.9 million were assigned to this industry. It is important to understand to what extent the expense is an investment and when is it rather a loss.[5.]

We analyzed transportation expenses from 2005 to 2015 and determined which types of transportation are bringing the biggest income and which ones represent the bigger loss.[5.] The information was well organized, so the cleaning was simple, some columns had a lot of missing values but were not relevant to our investigation, so we were able to drop them. Interestingly public transit did not have any values for revenue, this makes sense because of the nature of the service. We decided that the best way to analyze this information was through the creation of pivot tables and see the trends throughout the years. Total revenue is consistently higher than Total expense, this means that at least for this time period the money allocated to the transportation industry in Canada can be considered an investment.

All modes of transportation
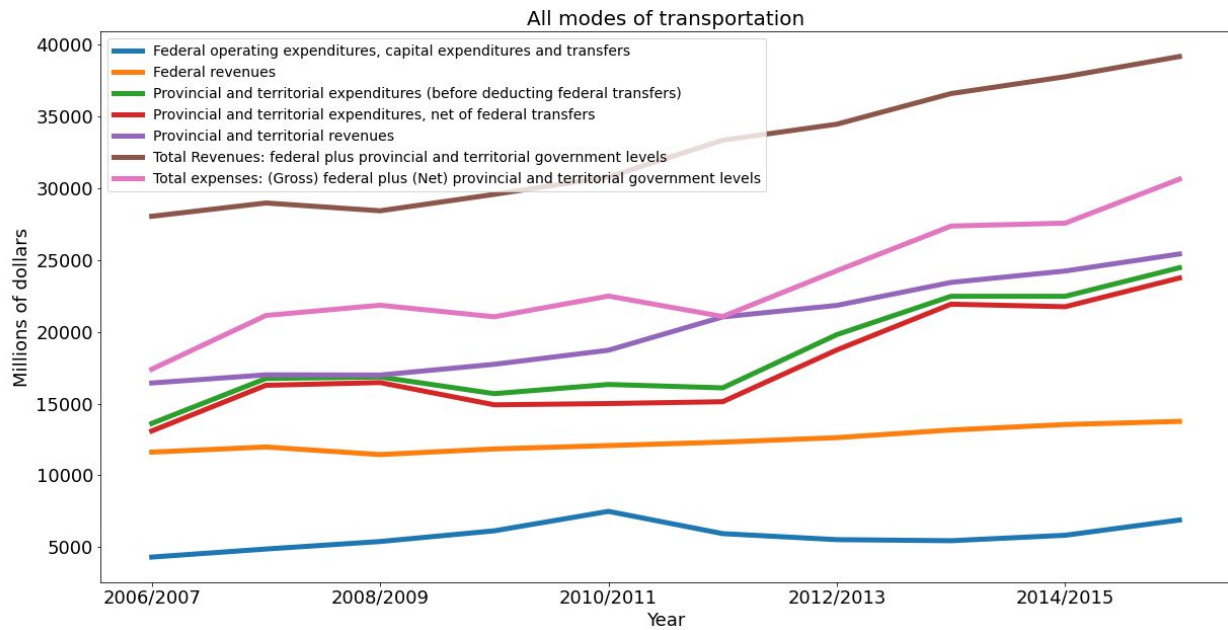
If we analyze more closely, we can see how Public transportation comes as a "Total loss" only because there's no revenue information, however, this expense gets taken care off using the revenue of other industries like "Road transport", one could conclude that the people using the roads (cars, trucks, etc) are contributing to create a better public transportation system.

Road transportation

Public transportation

We proceeded to calculate income as the difference between expenses and revenues and we can see which modes of transportation have been net positive throughout the years, and which ones represent an expense rather than an investment. Interestingly marine transport has consistently been a net negative for this period.
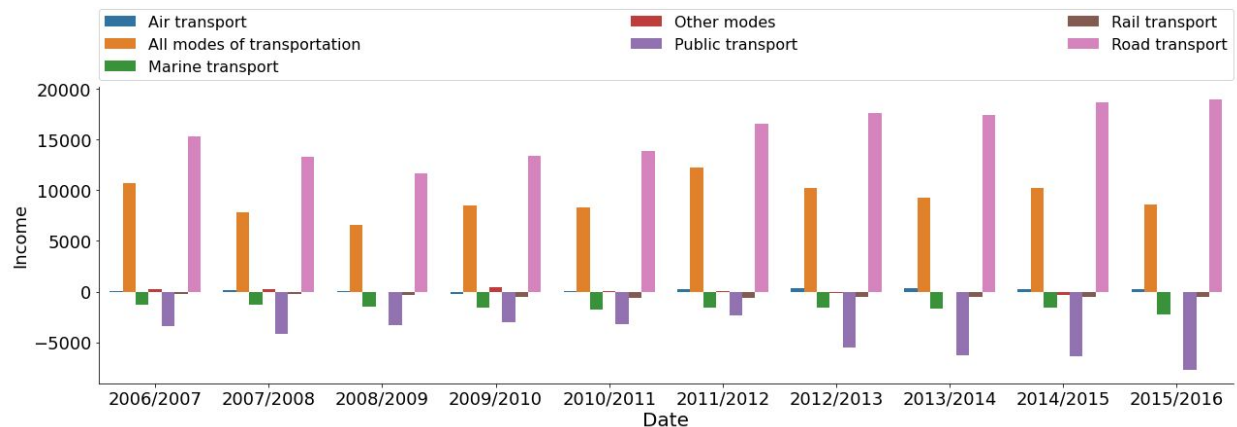

It seems like the investment in road transport, other modes of transportation and air transport are the most lucrative ones. Public transport represents only a "loss" but said loss can be compensated with the revenue from Road transport. Interestingly, the taxes and costs associated with driving a car help build our public transportation systems.

Transportation Safety

We wanted to look at transportation safety in this report, since it costs money to maintain public transit, clear roads, or build bike lanes to keep cyclists safe. As such it relates to our analysis of the cost of transportation and look for outliers in safety incidents in each mode of transportation. [6,7.]

Transportation safety is a joint effort of different parties: drivers, passengers, safety features of the equipment, road conditions, etc.. We are curious to see if transportation expenditures have a significant relationship with reducing/increasing transportation accidents.

The data for national/provincial collisions in 2016 and the transportation expenditures per provinces were compared. The original dataset of national collisions in 2016 had three columns to study fatalities and injuries per 100,000 people, per-billion kilometers and per 100,000 licensed drivers. We kept the first column as we wanted to investigate the fatality and injury rate population-wise. The dataset was already neatly organized, so it did not require more cleaning. The transportation expenditures per province dataset was adapted from the question of "Transportation spending".
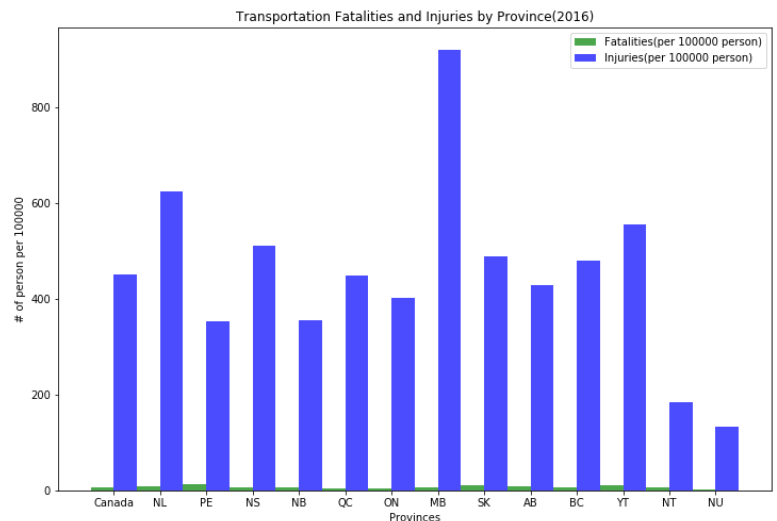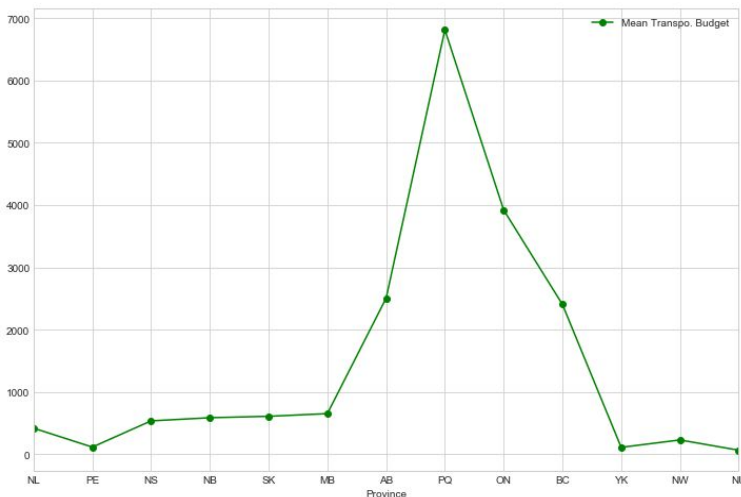
In the graph above, we can see that Manitoba witnessed the highest number of collision induced injuries, followed by Newfoundland and Labrador and Yukon. Compared with the mean transportation budget graph above, we can see that Manitoba, Saskatchewan, Nova Scotia and New Brunswick have spent almost the same for transportation, however, Manitoba has a significantly higher rate of collision induced fatalities and injuries. From this we conclude that although sufficient budget for transportation can bring better road conditions and transportation facilities, achieving transportation safety needs way more effort from drivers and traffic police.

Transportation Efficiency

There are many ways in which transportation can be efficient, and we are taking a look at a few of them. The first uses commute time as a proxy for efficiency, making the assumption that a shorter commute time means the transportation network gets more people to work faster. The second is a look at the breadth of choices available to people. Finally we look at environmental efficiency, investigating the relationship between expenditure on public transportation and greenhouse gas emissions.

We used data from the 2016 Canadian census to get a table of commute modes and commute times.[3,8.] The tables both had multiple columns as values: commute times or commute distances. Each observation was a mode of transportation with counts for each commute time or commute distance (e.g. 0-15 minutes, 15-30 minutes, etc). The data also had more modes of commuting than we needed. First, we filtered the rows to only use the modes of transportation we cared about: Cars, Public transit, Active transport, and Other. Then, we melted the data: going from values as columns, to a single row for each value, and a row for the counts. That is, we lengthened the data.

We have commute times and commute distances, so it was tempting to look at commute velocity. However, velocity is not a metric that transportation users necessarily care about if their commutes still take a long time. Thus, our first look at efficiency commute times, under the hypothesis that a shorter commute means a more efficient transportation network. We can't take into account the density of a city or town since our data is at the provincial level, thus we compare commute times for different commute modes in the same province.

Specifically, we looked at the commute time difference between driving and taking public transit to work, for each province. As seen in the graph below, driving is faster than public transit in all provinces, usually by a factor between 1.5 and 2. It is out of the scope of this report to analyze the socioeconomic reasons why someone would choose public transit over owning a car. Prince Edward Island has the most efficient public transit compared to driving, while Nunavut performs the worst.


Mean commute times by provinces
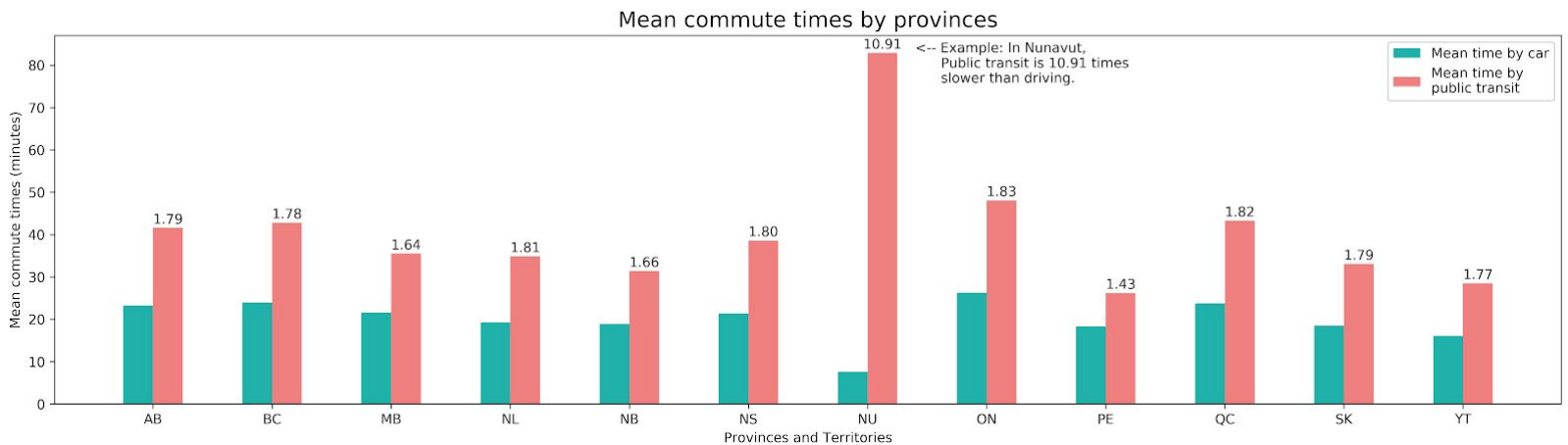
Commute distance and transportation usage rates

To analyze usage rates we normalized usage data to 100%. For example in Alberta, public transit seems to be the second most frequently used method of transportation.

area	commute_mode	
alberta	Active transport	6.287069
	Car, truck or van	81.482556
	Other method	1.277225
	Public transit	10.953151

We observed that for all provinces, Car was the most consistent method of transportation, which correlates with road transportation being the transportation area that provides most revenue to Canada. This result is consistent with other parts of this project.
We observed that there's variation regarding other methods of transportation, for instance in Nunavut and Yukon active transportation is the second most common method of transportation. Interestingly most people in Nunavut

travel 3 km or less, this would explain why most people are ok using resources like walking. In Yukon most people travel 5km or less, but still active transport is prevalent. People from Yukon seem to be the most active (at least in regard to how they commute on a day to day basis).
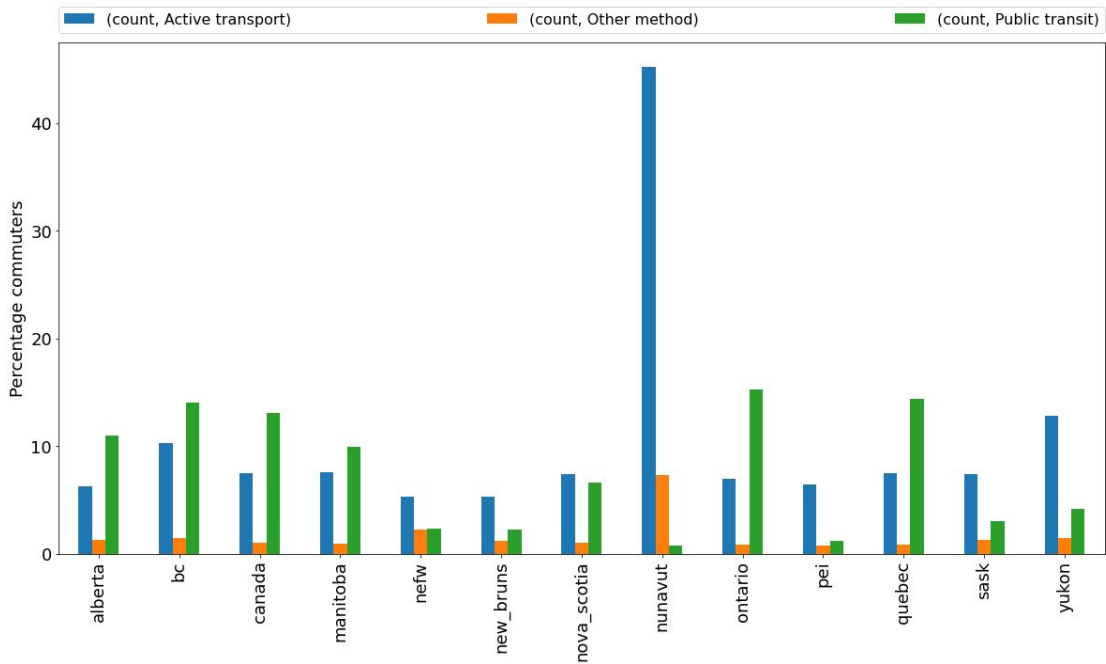
In Canada the most frequent commute distances are 1-3 km and 10 -15. Alberta, Nova Scotia, Quebec and Ontario are the biggest contributors for that.
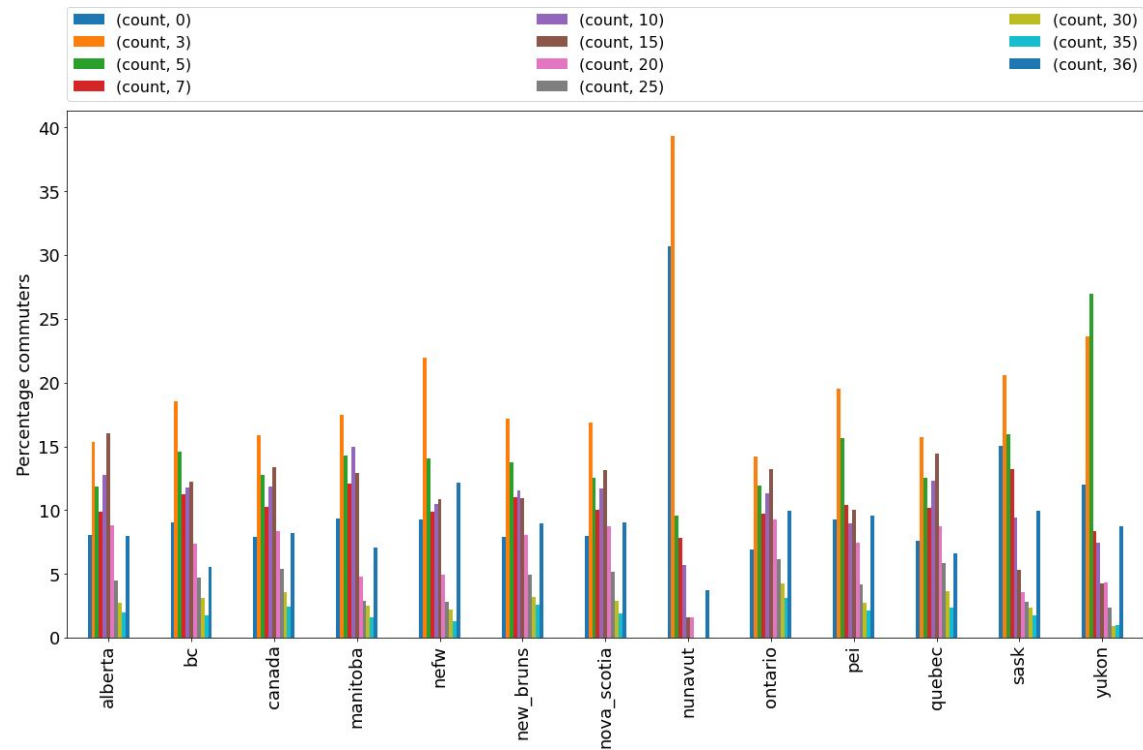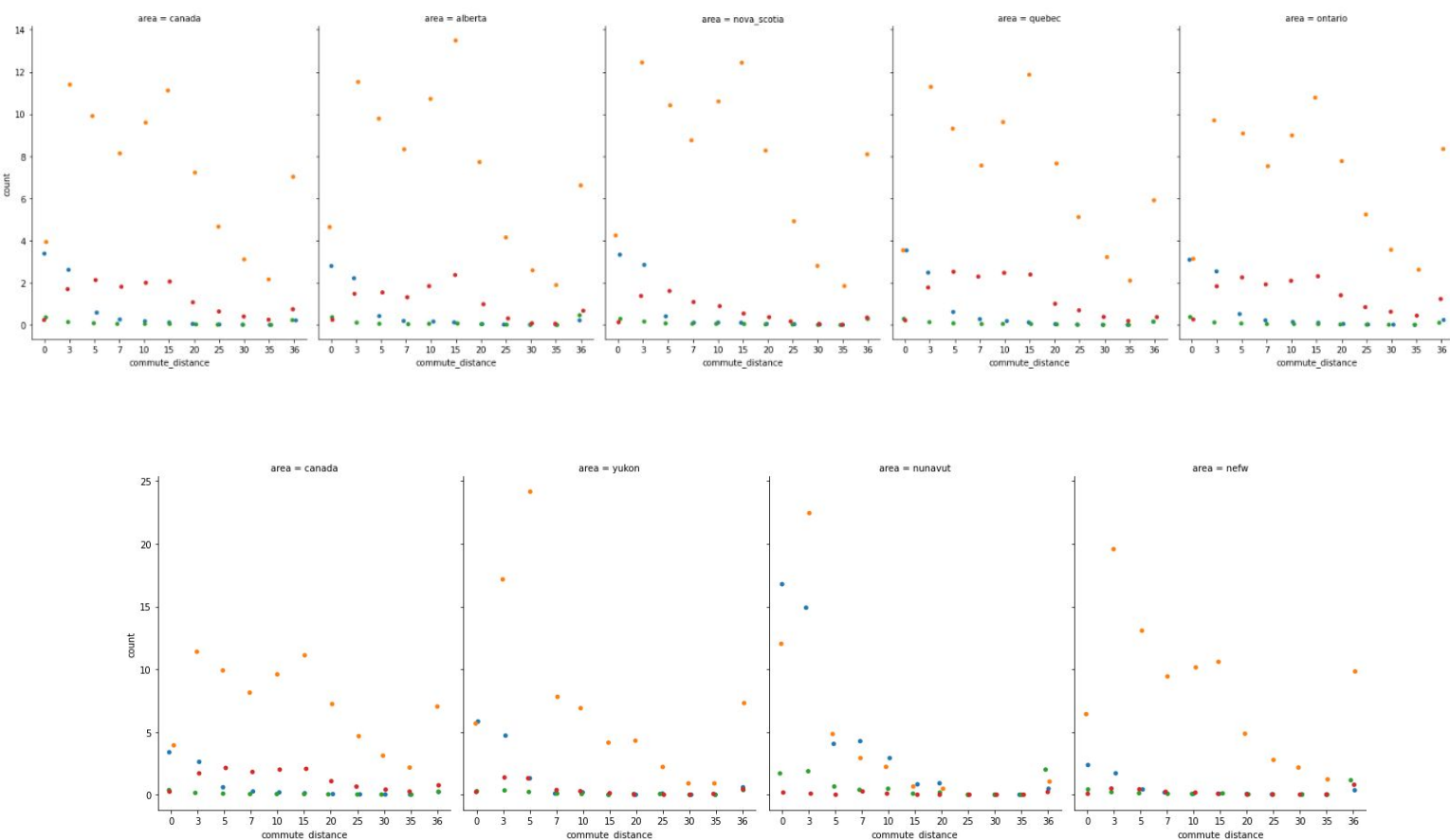
With Yukon, Nunavut, and Newfoundland being the most different trends.Regarding efficiency, under the assumption that communities have more efficient transit when they are more prone to take it, then it looks like Ontario is the one that uses it the most, followed by Quebec and Alberta.
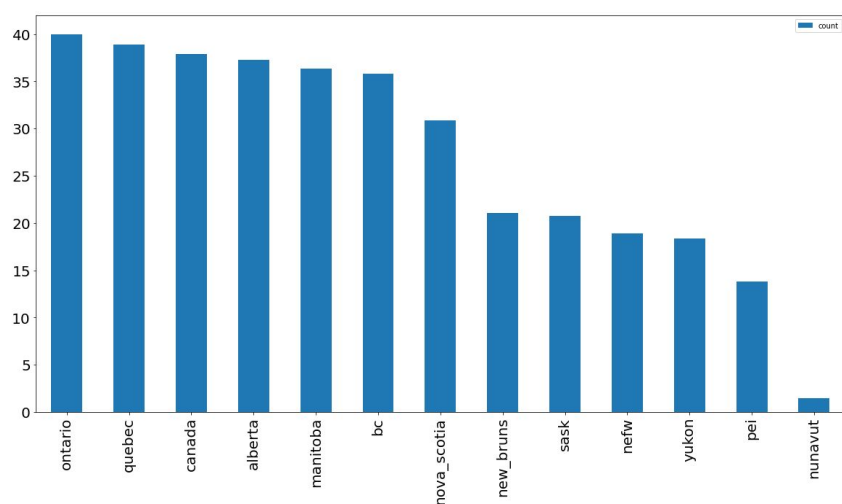
Finally, this graph allows us to identify how transportation frequency varies depending on the province, the norm was set by "Canada" as 100%.

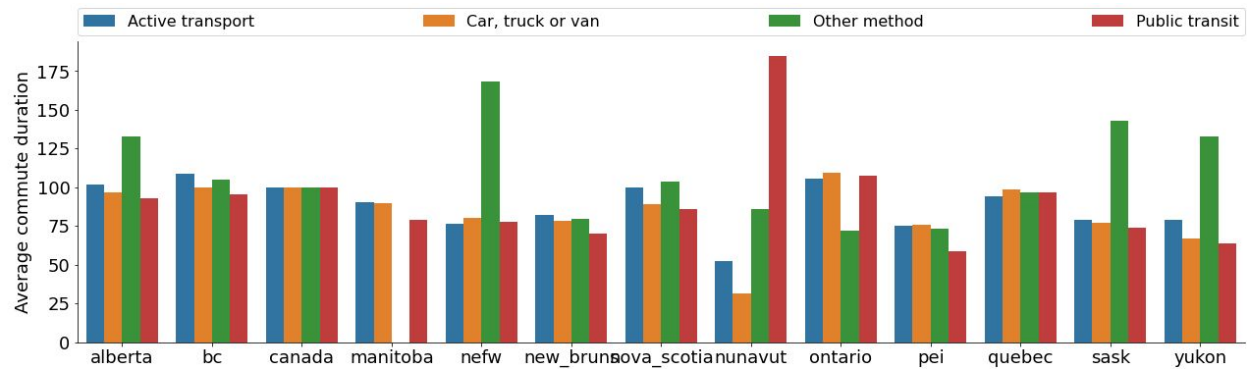If we consider the most used method as the most efficient one, car wins in every province, for Nunavut active transport is very close, and Ontario has the most efficient public transit.
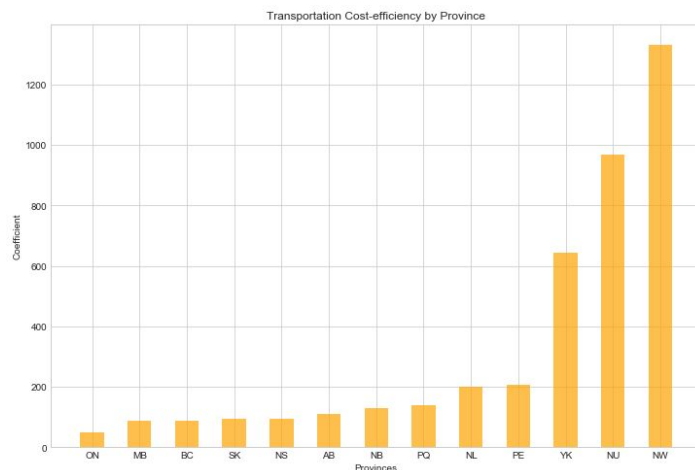
Transportation Variety

The cost-efficiency of the provincial transportation expenditures is strongly related to the variety of transportation methods that are available for residents to commute within the province and connect to the rest of the country. The availability of commuting by air, railway, bus, taxi, and cycling for each province was counted. A coefficient measurement in the form of:

$$ce = \frac{Mean\ provincial\ expenditure}{\#\ of\ modes\ of\ transportation}$$

was used to evaluate the cost-efficiency. When a province provides more modes of transportation while keeping the "mean provincial expenditure" to the minimum, it can be considered to be the most cost-effective way of spending the transportation expenses for a province.

Data from *Learn about the different types of transportation in Canada* [12] was used. The dataset is pretty small in size, so we organized by rows and columns, and no other cleaning was required.

Ontario managed to have the most various ways to commute, while keeping a modest transportation budget. This is followed by Manitoba, British Columbia, Saskatchewan, Nova Scotia, Alberta, New Brunswick, which all have similar cost-efficiency. The three territories, although spend slightly less than the majority of the provinces, are having the least cost-efficient transportation systems. Beside variety, future research can focus on how to improve other aspects of transportation that make up a good commuting system, such as punctuality, route planning, and accessibility to all available modes of transportation.

Greenhouse gas efficiency

Climate change is a global issue, and Canada has a part to play in reducing our greenhouse gas emissions. Transportation is one of those contributors, so we looked at greenhouse gas emissions of transportation as another measure of efficiency.

An academic report about the efficiency of Beijing's public transportation in China found that the usage rate of public transportation is also related to the number of elderly people in each region since this group of people relies more on public transportation.[9] Therefore, we will attempt to use multiple linear regression to build a model to find the relationship between annual population of seniors (65+), transportation expenditure and green-house gas emission. We chose multi linear regression to see which of the variables had the most effect on greenhouse gas emissions.

Provincial data on transportation expenditure, population of seniors, and greenhouse gas emissions was hard to find, so we used national data instead.[10,11] We downloaded the data, loaded it into python as three separate data frames and plotted them for an overview on how those variables changed by time. Greenhouse gas emissions and transportation expenditures were plotted between 2007 and 2016, note that seniors is plotted between 1970 and 2020. All three of the graphs show an upward trend, with the noticeable exception of greenhouse gas emissions between 2007 and 2009 - possibly due to the global recession.
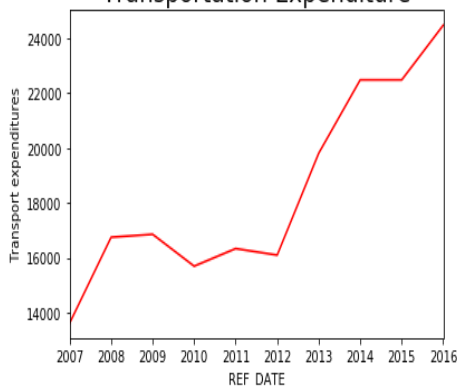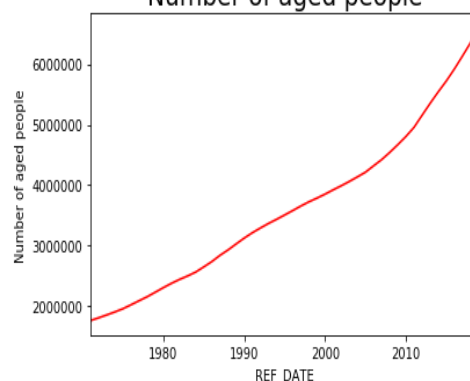

Since the graphs show an increase over time, we test the hypothesis that as the population of senior citizens that a monotone increase in national seniors and transportation expenditure should have a negative correlation with transportation green-house emission. However, we were unable to find data on the number of seniors as a percentage of citizens, and thus cannot say for certain that it is seniors who affect public transit use and greenhouse gas emissions. That being said, we ran the regression as follows:

$$Ghg\ Emissions\ =\ x_o\ +\ x_1 Trans\ exp\ +\ x_2 Num\ Seniors$$

To clean the data we cropped years between 2007 and 2016, created a new column for total greenhouse gas emissions. Then, the data was split into training and test parts. We then applied multi-linear regression to calculate the coefficients for transportation expenditure and number of seniors. Here is the result:

$$Ghg\ Emissions\ =\ x_o\ +\ (-0.000438) \cdot Trans\ exp\ +\ (0.000008) \cdot Num\ Seniors$$
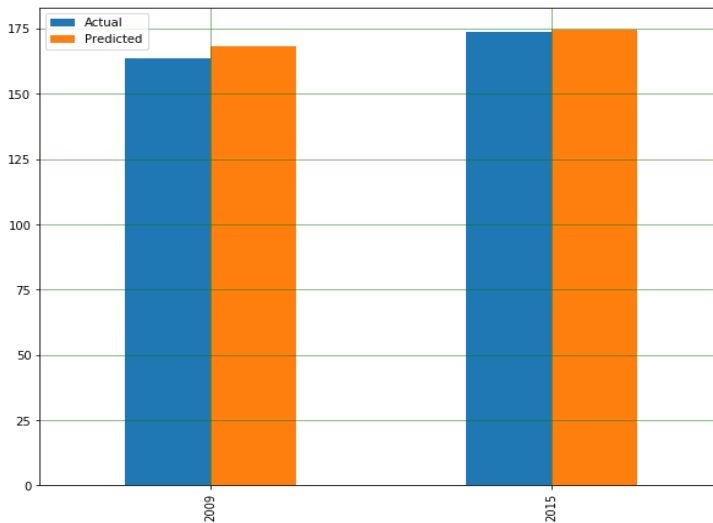
According to the analysis above, we see that the population of seniors in Canada is slightly positively correlated with transportation greenhouse gas emissions since the coefficient of number of seniors is positive. The coefficient of transportation expense is negatively correlated to the greenhouse gas emissions, which can show that by increasing the spending on transportation can reduce the pollution caused by transportation, especially public transportation. However, since the low volume of the data I have used in the research, the model might have a lower accuracy.

Conclusion

In this paper, we looked at Canada's transportation network - including who uses it, how much governments spend, and how efficient they are. We found that ubiquitously cars are the most popular and most efficient form of transportation for people. Due to the unique nature and geography, and funding structure, the territories proved to be outliers in many cases. We confirmed our hypothesis that public transportation spending efficiency improves as populations increase. Transportation revenue was demonstrated to return significant percentages of investment, making transportation overall an effective place to spend money for governments. Transportation safety turned out to be only loosely correlated with spending, thus we conclude that the burden of safety lies more on the citizens, not the government.

When analyzing efficiencies, we found that people in Yukon are the most likely to walk to work, while people in Ontario are most likely to take public transit, though in all provinces, driving was the most common mode of commuting. When looking at transportation variety, we found that Ontario provides the best ratio of dollars spent per number of modes of transportation. Finally, when looking at greenhouse gas emissions, we found that greenhouse gas emissions fall with increased expenditure on transportation, implying higher spending results in more efficient transportation.

In a future analysis, we believe it would be interesting to look at commute times more granularly, looking at individual distances and times to deduce efficiency for individual people. We would also like to compare Canada's transportation network to other countries, such as the USA, Japan, and UK, for their own unique transportation solutions.

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