Vaccination in the UK

Contents

1 Step 1 Find dataset

- Create a list of metrics for each dataset
- Look at the metrics

Lower Tier Local Authority (LTLA)

```
##  [1] "New people receiving 2nd dose"
##  [2] "New people vaccinated with a booster dose by publish date"
##  [3] "New people vaccinated complete by publish date"
##  [4] "New people fully vaccinated by vaccination date"
##  [5] "New people vaccinated 1st dose by publish date"
##  [6] "New people vaccinated with a first dose by vaccination date"
##  [7] "New people vaccinated 2nd dose by publish date"
##  [8] "New people vaccinated with a second dose by vaccination date"
##  [9] "New people vaccinated with a third dose by publish date"
## [10] "New people vaccinated with a booster dose plus new people vaccinated with a third dose by publish date"
## [11] "New people vaccinated with a booster or third dose by vaccination date"
## [12] "New vaccines given by publish date"
```

Nation

```
##  [1] "New people receiving 1st dose"
##  [2] "New people receiving 2nd dose"
##  [3] "New people vaccinated with a booster dose by publish date"
##  [4] "New people vaccinated complete by publish date"
##  [5] "New people fully vaccinated by vaccination date"
##  [6] "New people vaccinated 1st dose by publish date"
##  [7] "New people vaccinated with a first dose by vaccination date"
##  [8] "New people vaccinated 2nd dose by publish date"
##  [9] "New people vaccinated with a second dose by vaccination date"
## [10] "New people vaccinated with a third dose by publish date"
## [11] "New people vaccinated with a booster dose plus new people vaccinated with a third dose by publish date"
## [12] "New people vaccinated with a booster or third dose by vaccination date"
## [13] "New vaccines given by publish date"
```

So, as we can see, **some metrics are common**. I suggest finding out which metrics are the same for all datasets.

	ltla	msoa	nation	nhsRegion	nhsTrust	overview	region	utla
New people receiving 2nd dose	1	0	1	0	0	0	1	0
New people vaccinated with a booster dose by publish date	1	0	1	0	0	0	1	0
New people vaccinated complete by publish date	1	0	1	0	0	0	1	0
New people fully vaccinated by vaccination date	1	0	1	0	0	0	1	0
New people vaccinated 1st dose by publish date	1	0	1	0	0	0	1	0
New people vaccinated with a first dose by vaccination date	1	0	1	0	0	0	1	0
New people vaccinated 2nd dose by publish date	1	0	1	0	0	0	1	0
New people vaccinated with a second dose by vaccination date	1	0	1	0	0	0	1	0
New people vaccinated with a third dose by publish date	1	0	1	0	0	0	1	0
New people vaccinated with a booster dose plus new people vaccinated with a third dose by publish date	1	0	1	0	0	0	1	0
New people vaccinated with a booster or third dose by vaccination date	1	0	1	0	0	0	1	0
New vaccines given by publish date	1	0	1	0	0	0	1	0
New people receiving 1st dose	0	0	1	0	0	0	1	0

- Add new metrics in a common list
- Build zero-matrix, which dimension is the count of metrics x the count of area types
- Show links

Look at the result

First of all, I am interested in data about the **first jab**. **So, I need to look at the datasets:**

- Build zero-matrix, which dimension is the count of metrics x the count of area types

```
## [1] "Lower Tier Local Authority (LTLA)"
## [1] "Nation"
## [1] "Region"
```

2 Step 2 Ask something

I live in Bristol. What do I know about Bristol?

- This city is a part of the UK, England, and South West.
- There are two universities.
- The city rests every summer when students come back to their homes and works hardly elsewhen.

So, I am interested in data about the UK, England, South West, and Bristol.

Question 0: Are there dependencies between academic year events and vaccination waves? Does the vaccination depend on holidays?

I was vaccinated by

- the first dose on 8 August 2021,
- the second dose on 3 October 2021,
- the booster dose on 8 January 2022.

Question 1: How many people got their jabs with me?

I got the first and the second jabs on Sunday. There were fewer people in the vaccination centre. When I got the third jab on Saturday, there was a big queue.

Question 2: When do people prefer to get a jab: weekdays or weekends/Saturdays or Sundays?

Question 3: Is there something illogical in data?

3 Step 3 Look at the datasets

3.1 Region

As we can see on the website, Region metrics are available for regions of England. I am interested in the South West and metrics that start with "New":

```
## [1] "areaCode"
## [2] "areaName"
## [3] "areaType"
## [4] "date"
## [5] "newPeopleVaccinatedFirstDoseByVaccinationDate"
## [6] "newPeopleVaccinatedSecondDoseByVaccinationDate"
## [7] "newPeopleVaccinatedThirdInjectionByVaccinationDate"
```

We have additional columns. Let's look at them.

areaCode

```
## [1] "E12000009"
```

areaName

```
## [1] "South West"
```

areaType

```
## [1] "region"
```

So, we do not need to look at them in the future because these columns are used for filtering that we have already done on the website.

Let's prepare data for the plotting.

- Rename columns and columns

- Create long table

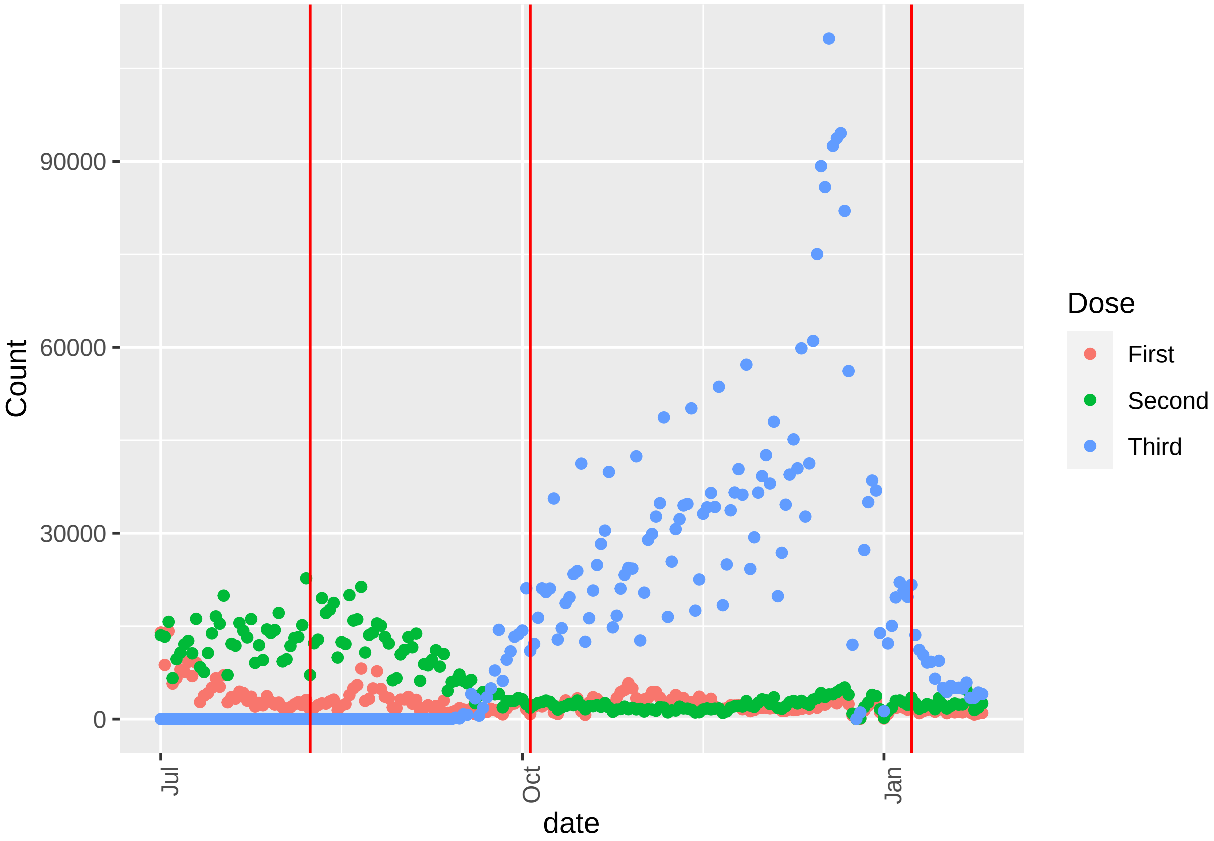
Let's plot something.

areaCode	areaName	areaType	date	First	Second	Third	MonthYear
E12000009	South West	region	2022-01-26	986	2520	4034	1.2022
E12000009	South West	region	2022-01-25	899	1845	4283	1.2022
E12000009	South West	region	2022-01-24	723	1445	3441	1.2022
E12000009	South West	region	2022-01-23	1035	3007	3439	1.2022
E12000009	South West	region	2022-01-22	1822	4709	5896	1.2022
E12000009	South West	region	2022-01-21	1085	2362	4944	1.2022

date	MonthYear	Dose	Count
2022-01-26	1.2022	First	986
2022-01-25	1.2022	First	899
2022-01-24	1.2022	First	723
2022-01-23	1.2022	First	1035
2022-01-22	1.2022	First	1822
2022-01-21	1.2022	First	1085

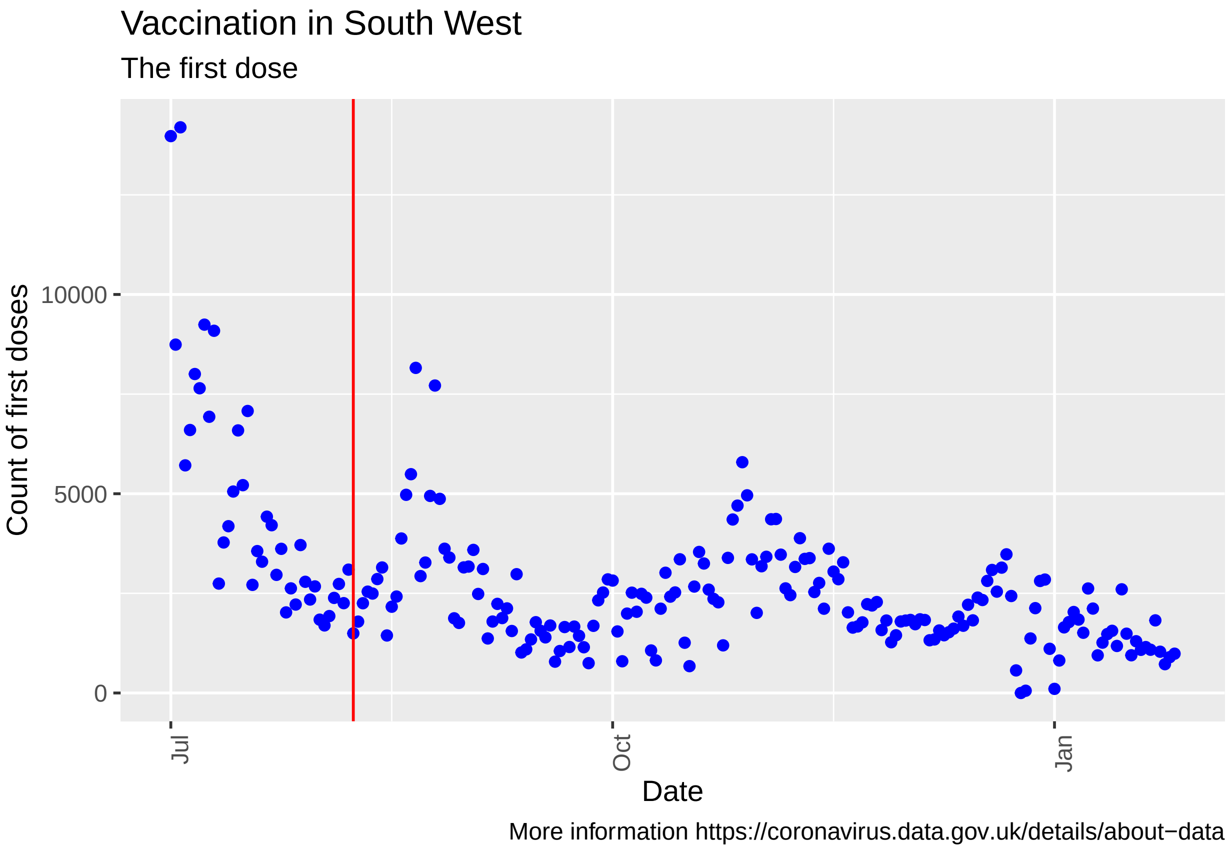
3.1.1 Question 0

Are there dependencies between academic year events and vaccination waves? Does the vaccination depend on holidays?

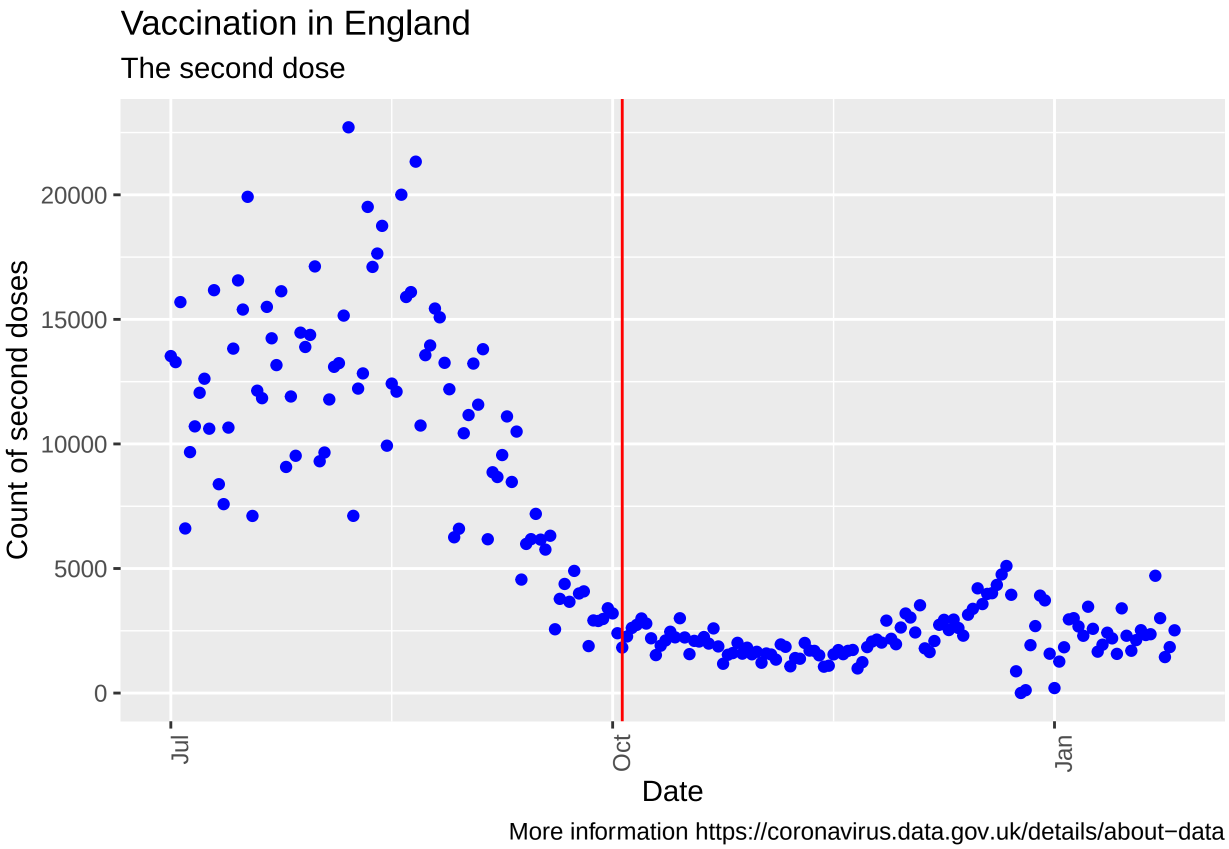


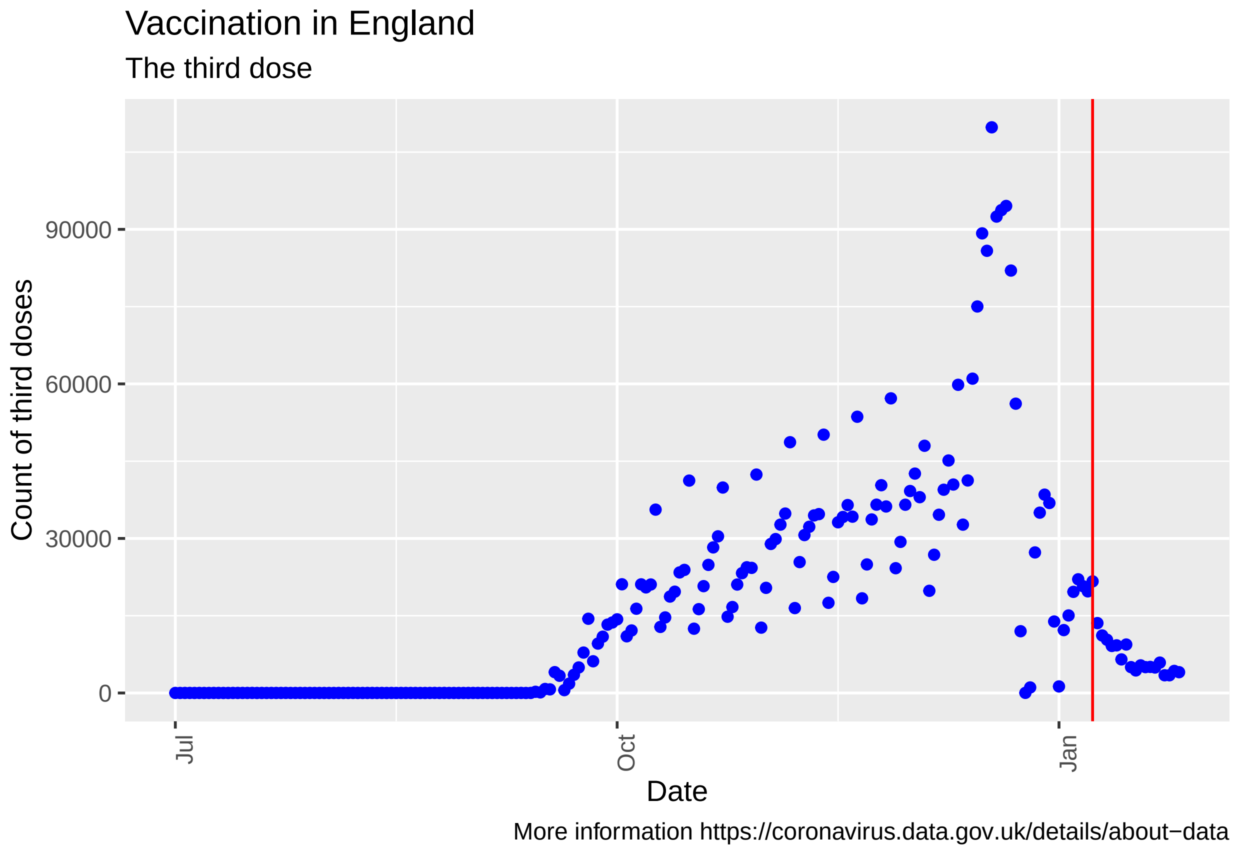
The result is not beautiful because of the active growth of the third jabs count at the end of 2021.

Let's plot them separately.



It is so interesting why the graph is wavy.

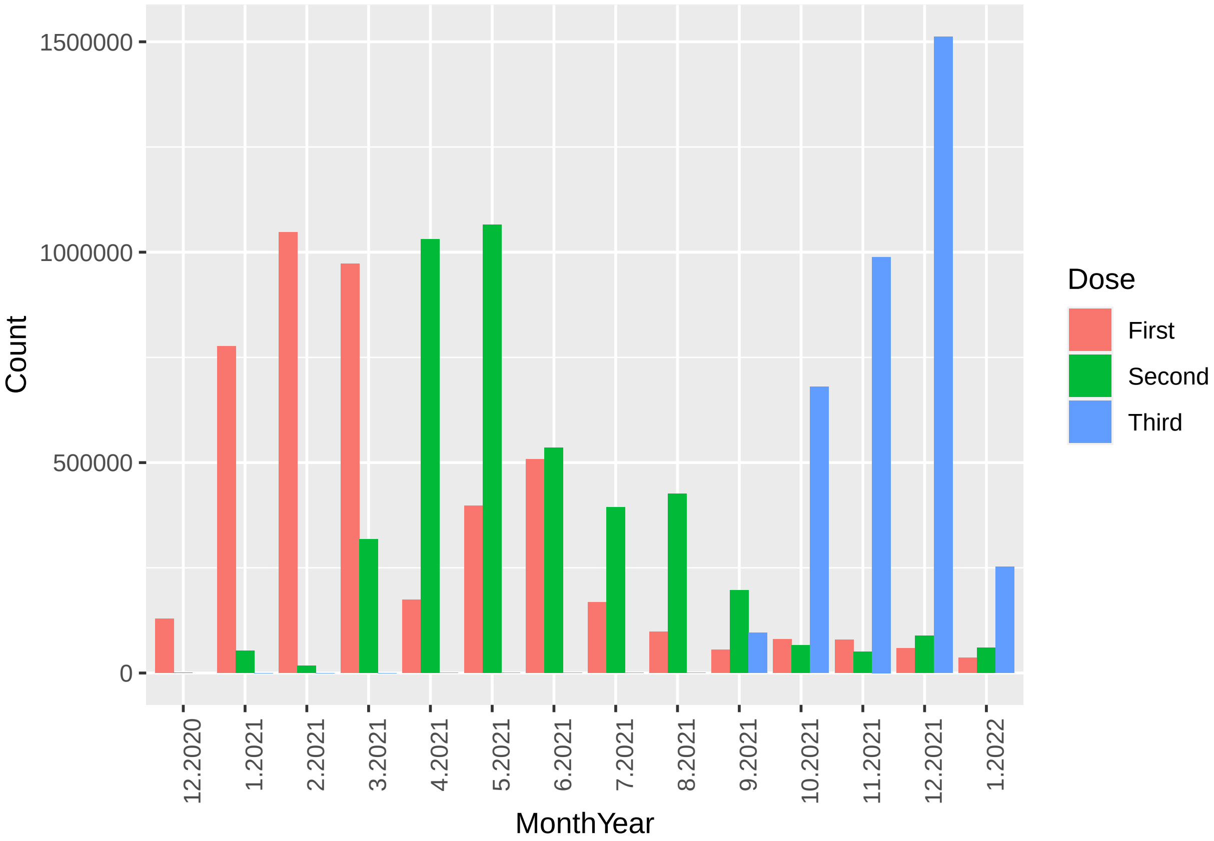

Vaccination in England
The second dose
Count of second doses
20000
15000
10000
5000
0
Jul
Oct
Jan
Date
More information https://coronavirus.data.gov.uk/details/about−data



We can see when the active phase of vaccination by the third dose started.

Let’s calculate the date.

```
## Warning: Removed 1 rows containing missing values (geom_col).
```


Count
1500000
1000000
500000
0
12.2020
1.2021
2.2021
3.2021
4.2021
5.2021
6.2021
7.2021
8.2021
9.2021
10.2021
11.2021
12.2021
1.2022
MonthYear
Dose
First
Second
Third

4 Step 4 Machine learning

4.1 Step 0: Read the dataset

Read csv-file

Look at the first row of the dataset

	areaCode	areaName	areaType	newPeopleVaccinatedFirstDoseByVaccinationDate	newPeopleVaccinatedSecondDoseByVaccinationDate	ne
2022-01-26	E12000009	South West	region	986	2520	

Drop unnecessary columns: areaCode, areaName, areaType.

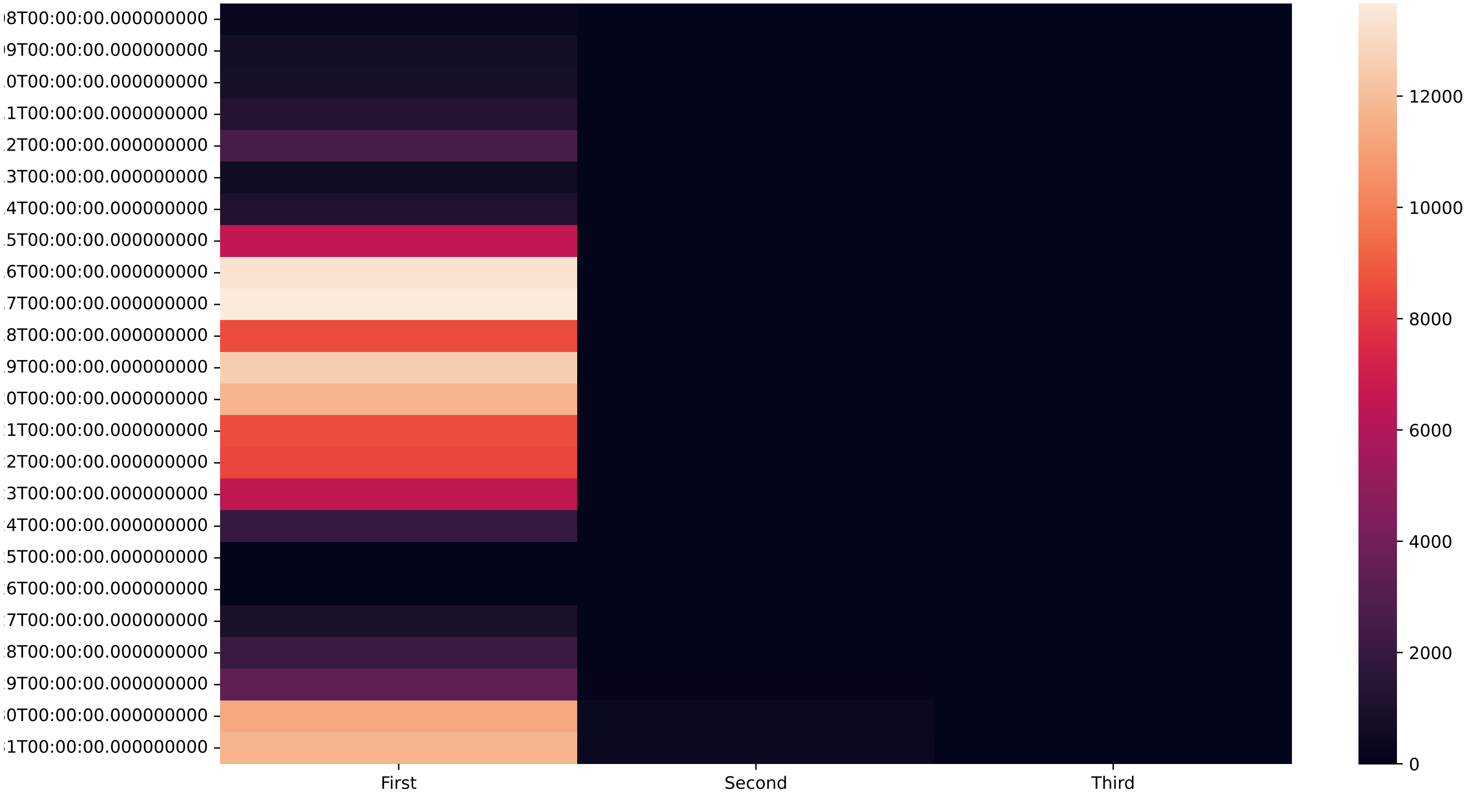
Rename columns newPeopleVaccinatedFirstDoseByVaccinationDate -> First, newPeopleVaccinatedSecondDoseByVaccinationDate -> Second, newPeopleVaccinatedThirdInjectionByVaccinationDate -> Third

Replace Na values

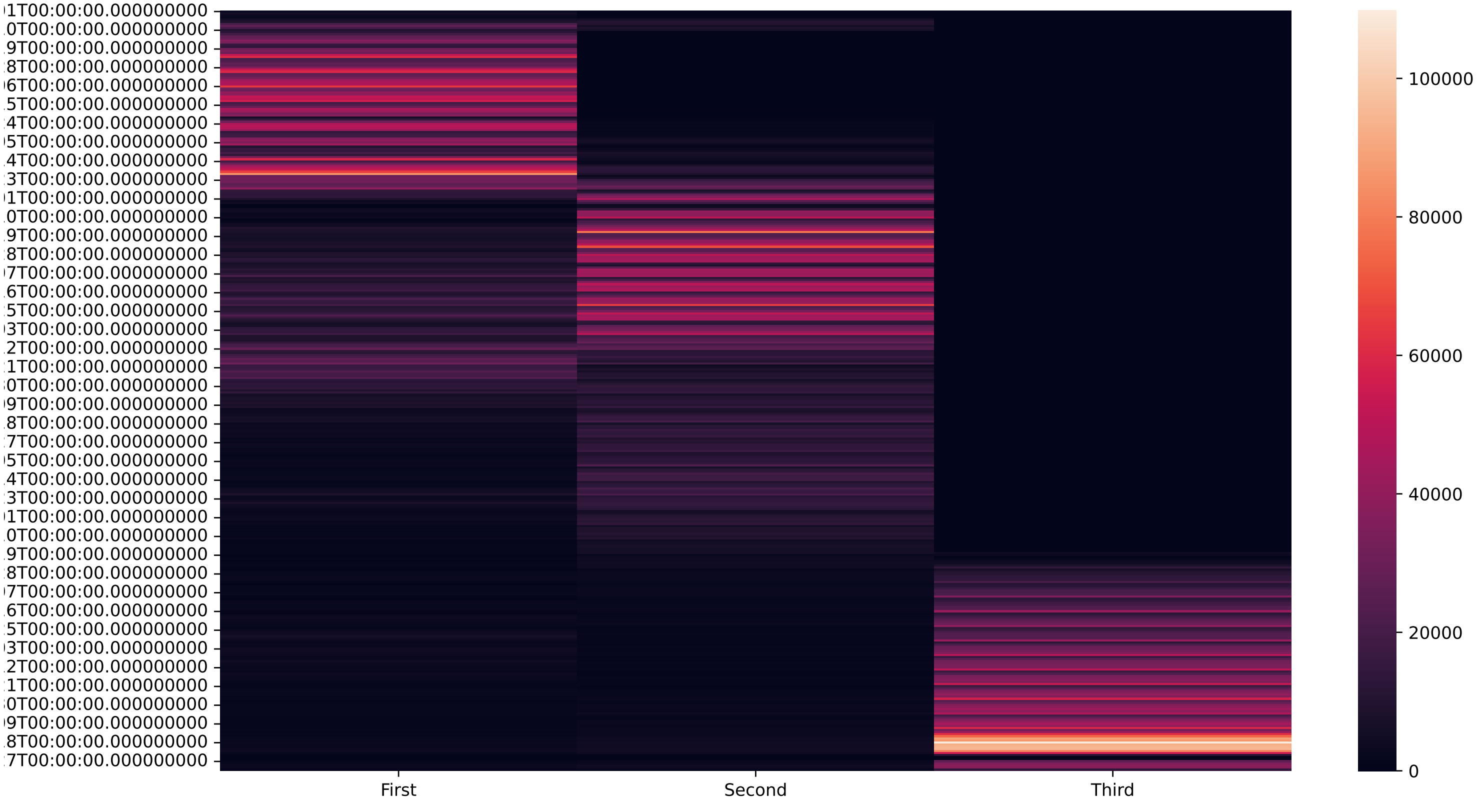
Look at the final version of the dataset

	First	Second	Third
2022-01-26	986	2520	4034

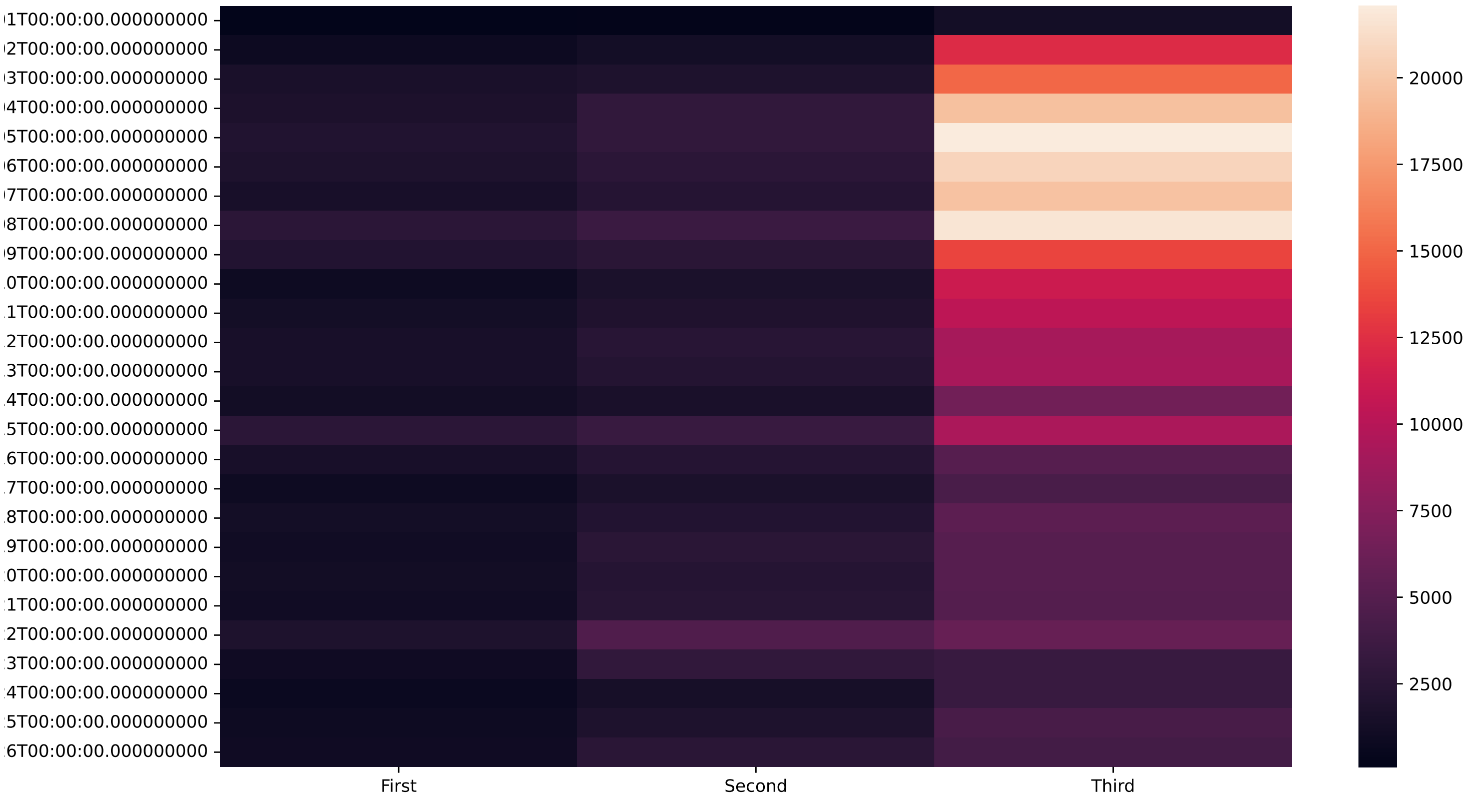
```
‘‘‘python
plt.figure(figsize=(14,8))
sns.heatmap(data=dataset.loc[[date for date in dataset.index if date.year==2020],:].sort_index())
```



```
plt.figure(figsize=(14,8))
sns.heatmap(data=dataset.loc[[date for date in dataset.index if date.year==2021],:].sort_index())
```



```
plt.figure(figsize=(14,8))
sns.heatmap(data=dataset.loc[[date for date in dataset.index if date.year==2022],:].sort_index())
```



## Step 1: Work with dates. Engineer Datatime Features

Get features: 1) Year 2) Month 3) Day etc.

```
dataset['Year'] = dataset.index.year
```

```
dataset['Month'] = dataset.index.month
```

```
dataset['Day'] = dataset.index.day
```

```
dataset['DayOfYear'] = dataset.index.dayofyear
```

```
dataset['WeekOfYear'] = dataset.index.weekofyear
```

```
## <string>:1: FutureWarning: weekofyear and week have been deprecated, please use DatetimeIndex.isocalendar().week instead, which returns
```

```
dataset['Weekday'] = dataset.index.weekday
```

```
weekdays = {0: 'Monday',
            1: 'Tuesday',
            2: 'Wednesday',
            3: 'Thursday',
            4: 'Friday',
            5: 'Saturday',
            6: 'Sunday'}




for dose in ["First", "Second", "Third"]:
    weekday_mean = dataset.groupby('Weekday')[dose].mean()
    weekday_mean = weekday_mean.rename(index=weekdays)
    plt.figure(figsize=(14,8))
    plt.title(dose)
    sns.barplot(x=weekday_mean.index, y=weekday_mean)
    plt.xticks(rotation=45)
```

```
## <Figure size 2800x1600 with 0 Axes>
## Text(0.5, 1.0, ’First’)
## <AxesSubplot:title={’center’:’First’}, xlabel=’Weekday’, ylabel=’First’>
## (array([0, 1, 2, 3, 4, 5, 6]), [Text(0, 0, ’Monday’), Text(1, 0, ’Tuesday’), Text(2, 0, ’Wednesday’), Text(3, 0, ’Thursday’), Text(4, 0
## <Figure size 2800x1600 with 0 Axes>
## Text(0.5, 1.0, ’Second’)
## <AxesSubplot:title={’center’:’Second’}, xlabel=’Weekday’, ylabel=’Second’>
## (array([0, 1, 2, 3, 4, 5, 6]), [Text(0, 0, 'Monday'), Text(1, 0, 'Tuesday'), Text(2, 0, 'Wednesday'), Text(3, 0, 'Thursday'), Text(4, 0
## <Figure size 2800x1600 with 0 Axes>
## Text(0.5, 1.0, 'Third')
## <AxesSubplot:title={'center':'Third'}, xlabel='Weekday', ylabel='Third'>
## (array([0, 1, 2, 3, 4, 5, 6]), [Text(0, 0, 'Monday'), Text(1, 0, 'Tuesday'), Text(2, 0, 'Wednesday'), Text(3, 0, 'Thursday'), Text(4, 0
```

```
dataset['Quarter'] = dataset.index.quarter
```

```
dataset['IsMonthStart'] = dataset.index.is_month_start
```

```
dataset['IsMonthEnd'] = dataset.index.is_month_end
```

Look at the dataset with new features

```
dataset.head()
```

```
##             First  Second   Third  ...  Quarter  IsMonthStart  IsMonthEnd
## date                               ...
## 2022-01-26    986    2520  4034.0  ...        1         False       False
## 2022-01-25    899    1845  4283.0  ...        1         False       False
## 2022-01-24    723    1445  3441.0  ...        1         False       False
## 2022-01-23   1035    3007  3439.0  ...        1         False       False
## 2022-01-22   1822    4709  5896.0  ...        1         False       False
##
## [5 rows x 12 columns]
```

```
dataset.info()
```

```
## <class 'pandas.core.frame.DataFrame'>
## DatetimeIndex: 415 entries, 2022-01-26 to 2020-12-08
## Data columns (total 12 columns):
##  #   Column        Non-Null Count  Dtype
## ---  ------        --------------  -----
##  0   First         415 non-null    int64
##  1   Second        415 non-null    int64
##  2   Third         415 non-null    float64
##  3   Year         415 non-null    int64
##  4   Month        415 non-null    int64
##  5   Day          415 non-null    int64
##  6   DayOfYear    415 non-null    int64
##  7   WeekOfYear   415 non-null    int64
##  8   Weekday      415 non-null    int64
##  9   Quarter      415 non-null    int64
##  10  IsMonthStart  415 non-null    bool
##  11  IsMonthEnd   415 non-null    bool
## dtypes: bool(2), float64(1), int64(9)
## memory usage: 52.6 KB
```

What is about Missing values? For example, there may be only one dose per day.

4.2 Step 2: Explore the dataset

4.3 Step 3: Split sets, train a Machine Learning Model and Evaluate performance

Define necessary variables

```
feature_columns = ["Year", "Month", "Day", "Weekday", "IsMonthStart", "IsMonthEnd"]
y_list = ["First", "Second"]
model_list = ["DecisionTree", "RandomForest"]
estimators_list = [100,200,300,400,500]
results = {}
val_sets = {}
```

Prepare sets

```
source_python('prepare_sets.py')
```

Train and evaluate the model

```
source_python('train_model.py')
```

Train models using parameters

```
for y in y_list:
    train_X, val_X, train_y, val_y = prepare_sets(dataset, feature_columns, y)
    val_sets[(y, "val_X")] = val_X
    val_sets[(y, "val_y")] = val_y
    for model in model_list:
        if model != "RandomForest":
            results[(y,model,"mae", 0)], results[(y,model,"predictions", 0)], results[(y,model,"model", 0)] = train_model(train_X, val_X,
        else:
            for n in estimators_list:
                results[(y,model,"mae", n)], results[(y,model,"predictions", n)], results[(y,model,"model", n)] = train_model(train_X, val
```

Compare the score with the mean value of the column that we predicted.

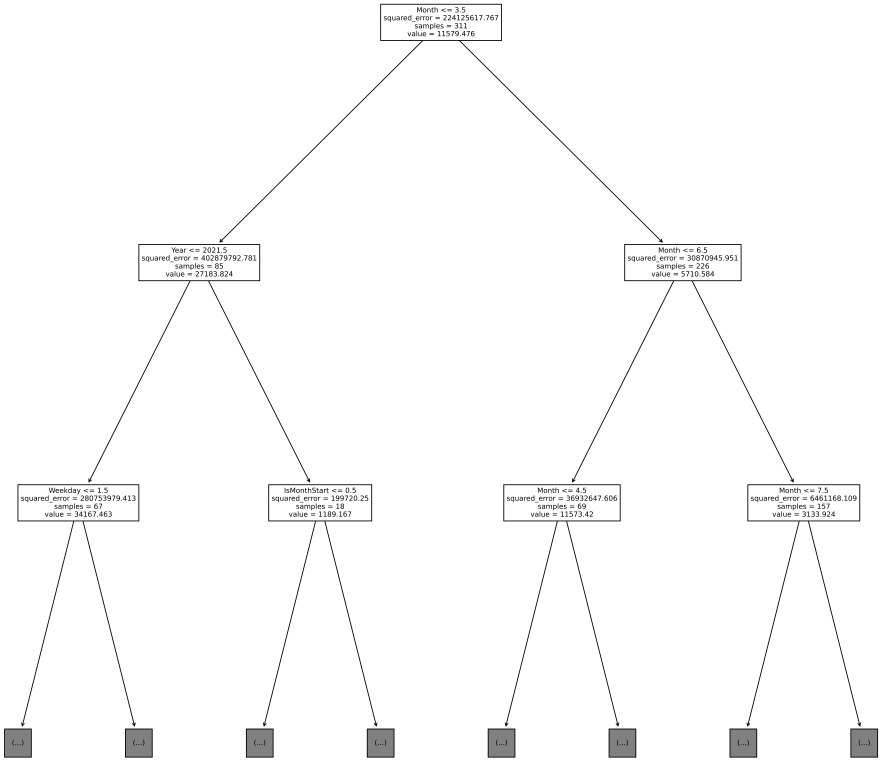
```
for res in results.keys():
    column, model, measure, treecount = res
    if measure == "mae":
        print(res, "Result: ", 1 - results[res]/dataset[column].mean())
```

```
## ('First', 'DecisionTree', 'mae', 0) Result:  0.6437087212771292
## ('First', 'RandomForest', 'mae', 100) Result:  0.751618587539483
## ('First', 'RandomForest', 'mae', 200) Result:  0.75634355378726
## ('First', 'RandomForest', 'mae', 300) Result:  0.7542008733902813
## ('First', 'RandomForest', 'mae', 400) Result:  0.7550162219639709
## ('First', 'RandomForest', 'mae', 500) Result:  0.754843479613817
## ('Second', 'DecisionTree', 'mae', 0) Result:  0.706121636338128
## ('Second', 'RandomForest', 'mae', 100) Result:  0.7715985048182643
## ('Second', 'RandomForest', 'mae', 200) Result:  0.776153470596447
## ('Second', 'RandomForest', 'mae', 300) Result:  0.7765567227604535
## ('Second', 'RandomForest', 'mae', 400) Result:  0.7751089448055306
## ('Second', 'RandomForest', 'mae', 500) Result:  0.7738541991708733
```

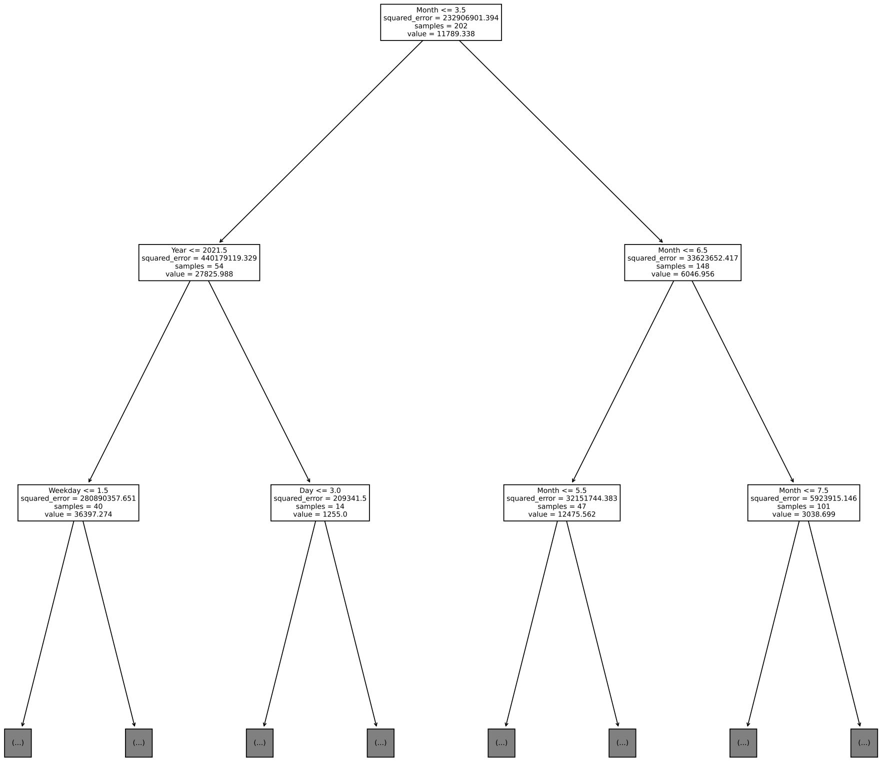
Look at the tree

```
# feature_columns is defined above
for y in y_list:
    for model in model_list:
        if model == "RandomForest":
            # one of the tree
            print('\n Dose:{}, Model:{} \n'.format(y, model))
            r = export_text(results[("First", "RandomForest", "model", 500)].estimators_[0], feature_names=feature_columns)
            print(r)
        else:
            print('\n Dose:{}, Model:{} \n'.format(y, model))
            r = export_text(results[(y, model, "model", 0)], feature_names=feature_columns)
            print(r)
```

```
plt.figure(figsize=(20,20))
# feature_columns is defined above
tree.plot_tree(results[("First", "DecisionTree", "model", 0)], max_depth=2, feature_names=feature_columns)
```

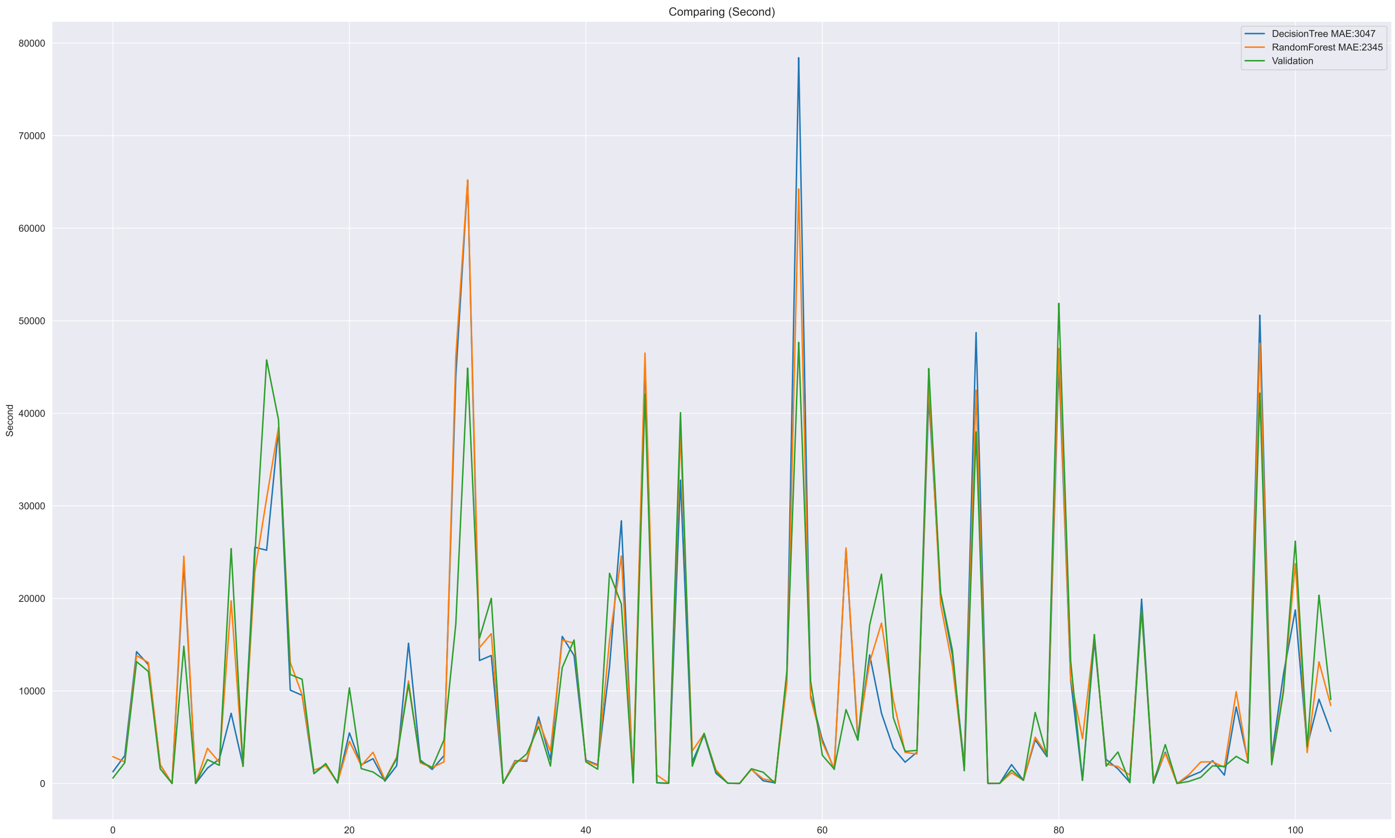

Month <= 3.5
squared_error = 224125617.767
samples = 311
value = 11579.476
Year <= 2021.5
squared_error = 402879792.781
samples = 85
value = 27183.824
Month <= 6.5
squared_error = 30870945.951
samples = 226
value = 5710.584
Weekday <= 1.5
squared_error = 280753979.413
samples = 67
value = 34167.463
IsMonthStart <= 0.5
squared_error = 199720.25
samples = 18
value = 1189.167
Month <= 4.5
squared_error = 36932647.606
samples = 69
value = 11573.42
Month <= 7.5
squared_error = 6461168.109
samples = 157
value = 3133.924
(...)
(...)
(...)
(...)
(...)
(...)
(...)
(...)

```
plt.figure(figsize=(20,20))
# feature_columns is defined above
tree.plot_tree(results[("First", "RandomForest", "model", 500)].estimators_[0], max_depth=2, feature_names=feature_columns)
```


Month <= 3.5
squared_error = 232906901.394
samples = 202
value = 11789.338
Year <= 2021.5
squared_error = 440179119.329
samples = 54
value = 27825.988
Month <= 6.5
squared_error = 33623652.417
samples = 148
value = 6046.956
Weekday <= 1.5
squared_error = 280890357.651
samples = 40
value = 36397.274
Day <= 3.0
squared_error = 209341.5
samples = 14
value = 1255.0
Month <= 5.5
squared_error = 32151744.383
samples = 47
value = 12475.562
Month <= 7.5
squared_error = 5923915.146
samples = 101
value = 3038.699
(...)
(...)
(...)
(...)
(...)
(...)
(...)
(...)

4.4 Step 4: Plot results

```
for y in y_list:
    # set size, style and title
    plt.figure(figsize=(25,15))
    sns.set_style("darkgrid")
    plt.title('{} ({})'.format("Comparing", y))
    # plot predictions
    for model in model_list:
        if model == "RandomForest":
            sns.lineplot(data=results[(y, model, "predictions", 500)], label='{} MAE:{}'.format(model, round(results[(y, model, "mae", 500
        else:
            sns.lineplot(data=results[(y, model, "predictions", 0)], label='{} MAE:{}'.format(model, round(results[(y, model, "mae", 0)]),
    # plot validation set
    val_sets[(y, "val_y")].index=range(0,len(val_sets[(y, "val_y")]))
    sns.lineplot(data=val_sets[(y, "val_y")], label="Validation")
    # add legend
    plt.legend()
```


Comparing (Second)
DecisionTree MAE:3047
RandomForest MAE:2345
Validation
Second
80000
70000
60000
50000
40000
30000
20000
10000
0
0
20
40
60
80
100

4.5 Step 5: Improve models by changing the dataset

4.5.1 Work with features

```
dataset.info()
```

```
## <class 'pandas.core.frame.DataFrame'>
## DatetimeIndex: 415 entries, 2022-01-26 to 2020-12-08
## Data columns (total 12 columns):
##  #   Column        Non-Null Count  Dtype
## ---  ------        --------------  -----
##  0   First         415 non-null    int64
##  1   Second        415 non-null    int64
##  2   Third         415 non-null    float64
##  3   Year          415 non-null    int64
##  4   Month         415 non-null    int64
##  5   Day           415 non-null    int64
##  6   DayOfYear     415 non-null    int64
##  7   WeekOfYear    415 non-null    int64
##  8   Weekday       415 non-null    int64
##  9   Quarter       415 non-null    int64
##  10  IsMonthStart  415 non-null    bool
##  11  IsMonthEnd    415 non-null    bool
## dtypes: bool(2), float64(1), int64(9)
## memory usage: 52.6 KB
```

Define necessary variables

```
feature_columns = ["Weekday", "Year", "DayOfYear"]
y_list = ["First", "Second"]
model_list = ["DecisionTree", "RandomForest"]
estimators_list = [100,200,300,400,500]
results = {}
val_sets = {}
```

Prepare sets and Train models

```
for y in y_list:
    train_X, val_X, train_y, val_y = prepare_sets(dataset, feature_columns, y)
    val_sets[(y, "val_X")] = val_X
    val_sets[(y, "val_y")] = val_y
    for model in model_list:
        if model != "RandomForest":
            results[(y,model,"mae", 0)], results[(y,model,"predictions", 0)], results[(y,model,"model", 0)] = train_model(train_X, val_X,
        else:
            for n in estimators_list:
                results[(y,model,"mae", n)], results[(y,model,"predictions", n)], results[(y,model,"model", n)] = train_model(train_X, val
```

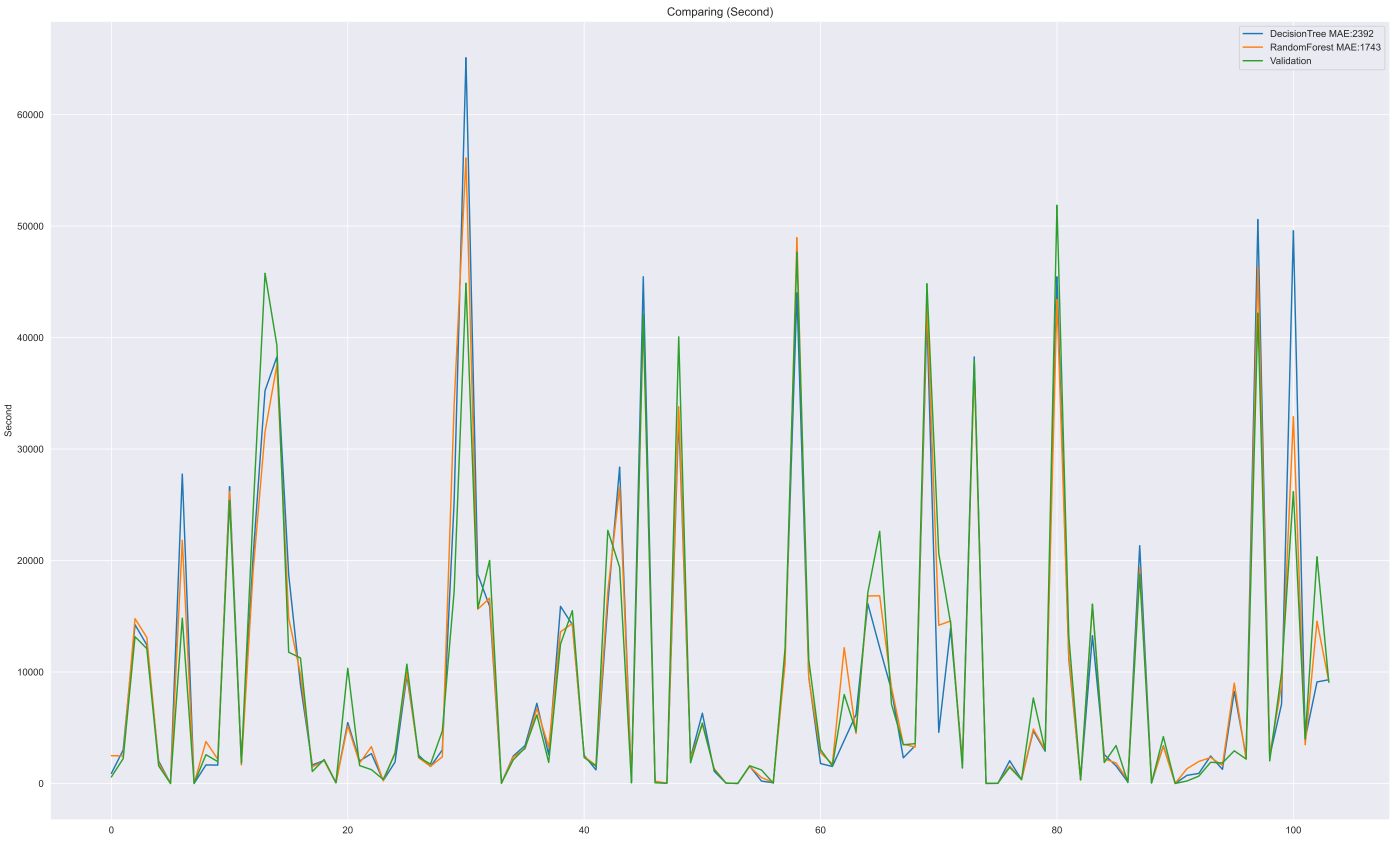
Compare the score with the mean value of the column that we predicted.

```
for res in results.keys():
    column, model, measure, treecount = res
    if measure == "mae":
        print(res, "Result: ", 1 - results[res]/dataset[column].mean())
```

```
## (’First’, ’DecisionTree’, ’mae’, 0) Result:  0.7248630326024768
## (’First’, ’RandomForest’, ’mae’, 100) Result:  0.7662734316499331
## (’First’, ’RandomForest’, ’mae’, 200) Result:  0.7831927047569076
## (’First’, ’RandomForest’, ’mae’, 300) Result:  0.7824191915655171
## (’First’, ’RandomForest’, ’mae’, 400) Result:  0.783001374743421
## (’First’, ’RandomForest’, ’mae’, 500) Result:  0.7837038702898657
## (’Second’, ’DecisionTree’, ’mae’, 0) Result:  0.7692636418171874
## (’Second’, ’RandomForest’, ’mae’, 100) Result:  0.8341621784974336
## (’Second’, ’RandomForest’, ’mae’, 200) Result:  0.8361849996061279
## (’Second’, ’RandomForest’, ’mae’, 300) Result:  0.8365889071806888
## (’Second’, ’RandomForest’, ’mae’, 400) Result:  0.8333133970971072
## (’Second’, ’RandomForest’, ’mae’, 500) Result:  0.8318561653086721
```

A combination of the following features give us the best result: * Weekday, * Year, * DayOfYear

```
for y in y_list:
    # set size, style and title
    plt.figure(figsize=(25,15))
    sns.set_style("darkgrid")
    plt.title('{} ({})'.format("Comparing", y))
    # plot predictions
    for model in model_list:
        if model == "RandomForest":
            sns.lineplot(data=results[(y, model, "predictions", 500)], label='{} MAE:{}'.format(model, round(results[(y, model, "mae", 500
        else:
            sns.lineplot(data=results[(y, model, "predictions", 0)], label='{} MAE:{}'.format(model, round(results[(y, model, "mae", 0)]),
    # plot validation set
    val_sets[(y, "val_y")].index=range(0,len(val_sets[(y, "val_y")]))
    sns.lineplot(data=val_sets[(y, "val_y")], label="Validation")
    # add legend
    plt.legend()
```



4.5.2 Work with missing values

```
dataset.index.min()
```

```
## Timestamp(’2020-12-08 00:00:00’)
```

```
dataset.index.max()
```

```
## Timestamp(’2022-01-26 00:00:00’)
```

```
dates = pd.date_range(dataset.index.min(),dataset.index.max(),freq='d')
```

```
dates
```

```
## DatetimeIndex([’2020-12-08’, ’2020-12-09’, ’2020-12-10’, ’2020-12-11’,
##                 ’2020-12-12’, ’2020-12-13’, ’2020-12-14’, ’2020-12-15’,
##                 ’2020-12-16’, ’2020-12-17’,
##                 ...
##                 ’2022-01-17’, ’2022-01-18’, ’2022-01-19’, ’2022-01-20’,
##                 ’2022-01-21’, ’2022-01-22’, ’2022-01-23’, ’2022-01-24’,
##                 ’2022-01-25’, ’2022-01-26’],
##                dtype=’datetime64[ns]’, length=415, freq=’D’)
```

```
len(dataset.index)
```

```
## 415
```

```
len(dates)
```

```
## 415
```

There are no missing dates.