Sanity Check:

AV Behavior in same scenario without modifying friction before/after friction implementation

Testing Parameters for clear-sunset

- cloudiness = 100
- precipitation = 0
- **precipitation_deposits = 0**
- sun_altitude_angle = 5
- sun_azimuth_angle = 0
- **wetness = 0**
- fog_density = 0
- wind_intensity = 10
- ice_thickness = 0

In [1]:
```
import os
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
%matplotlib inline
import scipy.stats
from scipy.stats import norm, binom, poisson
from dtaidistance import dtw
import json
```

After Reducing Friction Setup

In [7]:
```
rel_path = "./Data/Ghost Cutin/Rain Reduced Friction Exponential/route_highway_epoch24
os.path.isdir(rel_path)
```

Out[7]:
```
True
```

In [8]:
```
txt_lists_fric = []
for root, dirs, files in os.walk(rel_path):
    for file in files:
        if file.endswith(".txt"):
             with open(os.path.join(root, file), encoding = 'utf-8') as f:
                read_string = f.read()
                json_object = json.loads(read_string)
                txt_lists_fric.append(json_object)
```

In [9]:
```
count = 0
for txt in txt_lists_fric:
    if txt['_checkpoint']['records'][0]['status'] == 'Completed':
        count += 1
```

```
print("Average complete ratio:", count/100)
```

```
Average complete ratio: 1.0
```

In [10]:
```
count = 0
for txt in txt_lists_fric:
    count += txt['_checkpoint']['records'][0]['scores']['score_route']
print("Average score route:", count/100)
```

```
Average score route: 100.0
```

Setting up into list of DataFrames

In [11]:
```
os.chdir("C:\\Senior Research & Thesis\\Simulations")
```

In [12]:
```
os.path.isdir("./Data/Ghost Cutin/Rain Original/Simulations Rain PC/route_highway_epoc
```

Out[12]:
```
True
```

In [13]:
```
df_array_orig = np.empty(100, dtype=object)

for i in range(len(df_array_orig)):
    df_array_orig[i] = pd.DataFrame()
```

In [14]:
```
dir_path = rel_path

# list to store files
res = []

# Iterate directory
run_index = 0
for path in os.listdir(dir_path):
    # check if current path is a file
    if not os.path.isfile(os.path.join(dir_path, path)):
        df = pd.DataFrame()
        for file in os.listdir(os.path.join(dir_path, path)):
            file_path = os.path.join(dir_path, os.path.join(path, file))
#             print("file_path", file_path)
            if "_ctl.csv" in file_path:
                df = pd.read_csv(file_path)
            elif "_cvip.csv" in file_path:
                temp = pd.read_csv(file_path)
                df = pd.concat([df, temp], axis=1)
            elif "_traj.csv" in file_path:
                temp = pd.read_csv(file_path)
                df = pd.concat([df, temp], axis=1)

        df_array_orig[run_index] = df
        run_index += 1
```

In [15]:
```
df_array_orig[0]
```

Out[15]:

	ts	agent_id	throttle	steer	brake	ts	agent_id	cvip	cvip_x	c
0	1439477	0	0.900000	-0.013041	0.0	1439477	0	500.491189	198.767441	-95.83
1	1439478	0	0.900000	-0.000515	0.0	1439478	0	5.595580	195.567444	-90.83
2	1439479	0	0.900000	-0.011084	0.0	1439479	0	5.592365	195.567444	-90.83
3	1439480	0	0.900000	-0.004769	0.0	1439480	0	5.589578	195.567444	-90.83
4	1439481	0	0.900000	0.000125	0.0	1439481	0	5.587154	195.567444	-90.83
...	...	...	...	...	...	...	...	...	...	
752	1440229	0	0.486201	-0.001529	0.0	1440229	0	54.770809	192.563019	97.78
753	1440230	0	0.497011	-0.001434	0.0	1440230	0	54.870044	192.558350	98.11
754	1440231	0	0.476958	-0.001659	0.0	1440231	0	54.968588	192.553375	98.44
755	1440232	0	0.471986	-0.002172	0.0	1440232	0	55.066513	192.548126	98.77
756	1440233	0	0.450362	-0.002484	0.0	1440233	0	55.163813	192.542572	99.11

757 rows × 17 columns

Original Friction Setup

In [16]:
```
txt_lists_orig = []
for root, dirs, files in os.walk("./Data/Ghost Cutin/Rain Original/Simulations Rain PC
    for file in files:
        if file.endswith(".txt"):
             with open(os.path.join(root, file), encoding = 'utf-8') as f:
                read_string = f.read()
                json_object = json.loads(read_string)
                txt_lists_orig.append(json_object)
```

In [17]:
```
count = 0
for txt in txt_lists_orig:
    if txt['_checkpoint']['records'][0]['status'] == 'Completed':
        count += 1
print("Average complete ratio:", count/100)
```

```
Average complete ratio: 1.0
```

In [18]:
```
count = 0
for txt in txt_lists_orig:
    count += txt['_checkpoint']['records'][0]['scores']['score_route']
print("Average score route:", count/100)
```

```
Average score route: 100.0
```

Setting up into list of DataFrames

In [19]:
```
df_array_fric = np.empty(100, dtype=object)

for i in range(len(df_array_orig)):
    df_array_fric[i] = pd.DataFrame()
```

In [21]:
```
os.path.isdir("./Data/Ghost Cutin/Rain Original/Simulations Rain PC/route_highway_epoc
```

Out[21]:
```
True
```

In [22]:
```
dir_path = './Data/Ghost Cutin/Rain Original/Simulations Rain PC/route_highway_epoch24

# list to store files
res = []

# Iterate directory
run_index = 0
for path in os.listdir(dir_path):
    # check if current path is a file
    if not os.path.isfile(os.path.join(dir_path, path)):
        df = pd.DataFrame()
        for file in os.listdir(os.path.join(dir_path, path)):
            file_path = os.path.join(dir_path, os.path.join(path, file))

#             print(file_path)

            if "_ctl.csv" in file_path:
                df = pd.read_csv(file_path)
            elif "_cvip.csv" in file_path:
                temp = pd.read_csv(file_path)
                df = pd.concat([df, temp], axis=1)
            elif "_traj.csv" in file_path:
                temp = pd.read_csv(file_path)
                df = pd.concat([df, temp], axis=1)

        df_array_fric[run_index] = df
        run_index += 1
```

In [23]:
```
df_array_fric[0]
```

Out[23]:

	ts	agent_id	throttle	steer	brake	ts	agent_id	cvip	cvip_x	c
0	1111515	0	0.900000	-0.010707	0.0	1111515	0	500.491189	198.767441	-95.83
1	1111516	0	0.900000	-0.000900	0.0	1111516	0	5.595580	195.567444	-90.83
2	1111517	0	0.900000	-0.011500	0.0	1111517	0	5.592365	195.567444	-90.83
3	1111518	0	0.900000	-0.004868	0.0	1111518	0	5.589578	195.567444	-90.83
4	1111519	0	0.900000	0.000147	0.0	1111519	0	5.587154	195.567444	-90.83
...	...	...	...	...	...	...	...	...	...	
752	1112267	0	0.477660	-0.001647	0.0	1112267	0	54.731224	192.563019	97.78
753	1112268	0	0.478471	-0.000942	0.0	1112268	0	54.830479	192.558350	98.11
754	1112269	0	0.467884	-0.001690	0.0	1112269	0	54.929054	192.553375	98.44
755	1112270	0	0.465332	-0.002328	0.0	1112270	0	55.027003	192.548126	98.77
756	1112271	0	0.453689	-0.002363	0.0	1112271	0	55.124354	192.542572	99.11

757 rows × 17 columns

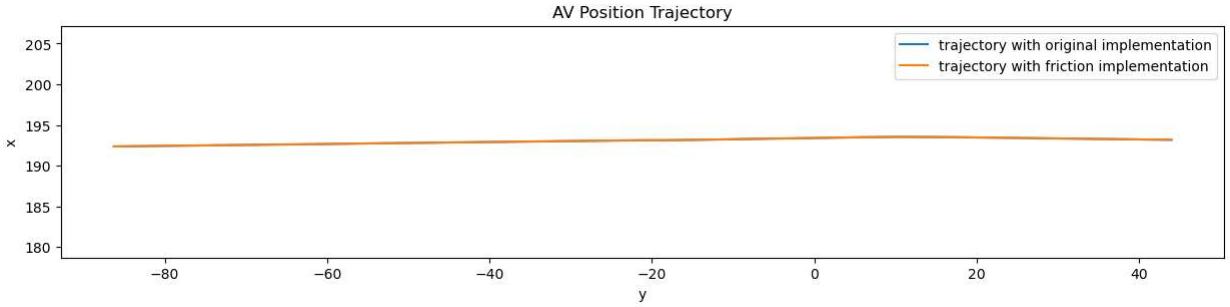
In [33]:
```
df_array_orig[0]['x']
```

Out[33]:
```
0      192.362411
1      192.362411
2      192.362411
3      192.362411
4      192.362411
          ...
752    193.186905
753    193.184387
754    193.181885
755    193.179367
756    193.176895
Name: x, Length: 757, dtype: float64
```

Comparison

In [55]:
```
plt.figure(figsize=(15,3))

df_orig_x = pd.DataFrame()
df_orig_y = pd.DataFrame()

for i in range(0, len(df_array_orig)):
    if(df_array_orig[i]['x'].dtypes == 'object' or df_array_orig[i]['y'].dtypes == 'ob
        print(i)
    else:
        if not df_array_orig[i]['x'].isnull().values.any() and not df_array_orig[i]['y
            df_orig_x["Run"+str(i)] = df_array_orig[i]['x']
            df_orig_y["Run"+str(i)] = df_array_orig[i]['y']

median_orig_x = df_orig_x.median(axis=1)
median_orig_y = df_orig_y.median(axis=1)
```

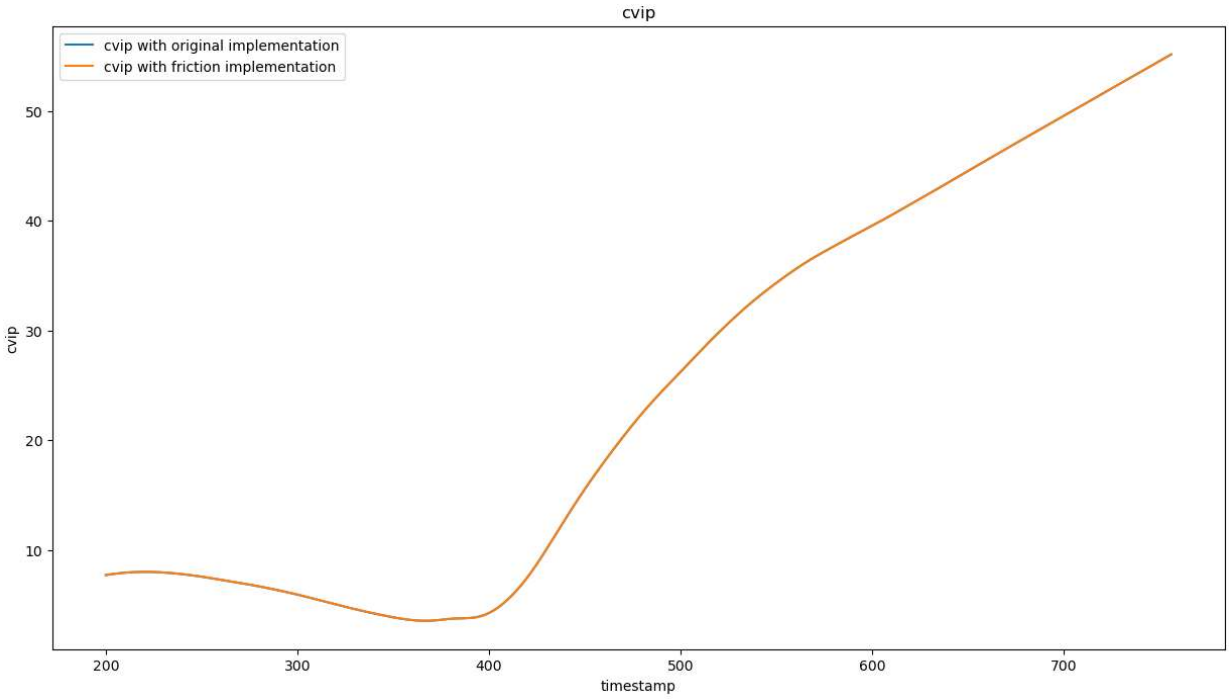
```
plt.plot(median_orig_y, median_orig_x)


df_fric_x = pd.DataFrame()
df_fric_y = pd.DataFrame()

for i in range(0, len(df_array_fric)):
    if(df_array_fric[i]['x'].dtypes == 'object' or df_array_fric[i]['y'].dtypes == 'ob
        print(i)
    else:
        if not df_array_fric[i]['x'].isnull().values.any() and not df_array_fric[i]['y
            df_fric_x["Run"+str(i)] = df_array_fric[i]['x']
            df_fric_y["Run"+str(i)] = df_array_fric[i]['y']

median_fric_x = df_fric_x.median(axis=1)
median_fric_y = df_fric_y.median(axis=1)

plt.plot(median_fric_y, median_fric_x)

plt.axis('equal')
plt.xlabel("y")
plt.ylabel("x")
plt.title("AV Position Trajectory")
plt.legend(["trajectory with original implementation", "trajectory with friction imple
plt.show()
```



Since no accident, check cvip

In [74]:
```
plt.figure(figsize=(15,8))

df_orig_cvip = pd.DataFrame()

for i in range(0, len(df_array_orig)):
    if(df_array_orig[i]['cvip'].dtypes == 'object'):
        print(i)
    else:
        if not df_array_orig[i]['cvip'].isnull().values.any():
            df_orig_cvip["Run"+str(i)] = df_array_orig[i]['cvip']

median_orig_cvip = df_orig_cvip.median(axis=1)


plt.plot(median_orig_cvip[200:])


df_fric_cvip = pd.DataFrame()

for i in range(0, len(df_array_fric)):
```

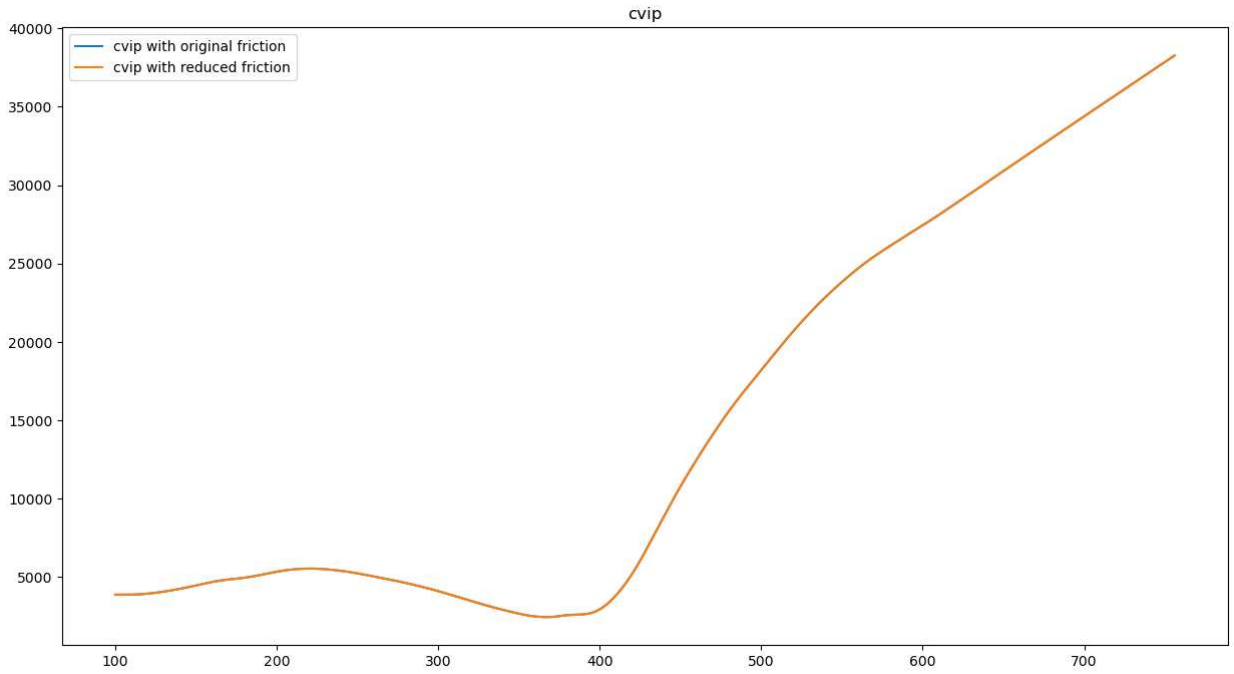
```
    if(df_array_fric[i]['cvip'].dtypes == 'object'):
        print(i)
    else:
        if not df_array_fric[i]['cvip'].isnull().values.any() :
            df_fric_cvip["Run"+str(i)] = df_array_fric[i]['cvip']

median_fric_cvip = df_fric_cvip.median(axis=1)

plt.plot(median_fric_cvip[200:])

# plt.axis('equal')
plt.xlabel("timestamp")
plt.ylabel("cvip")
plt.title("cvip")
plt.legend(["cvip with original implementation", "cvip with friction implementation"])
plt.show()
```



In [70]:

```
plt.figure(figsize=(15,8))

df_avg_orig_cvip = df_array_orig[0]['cvip']
count = 0

for i in range(1, len(df_array_orig)):
    if(df_array_orig[i]['cvip'].dtypes == 'object'):
        print(i)
    else:
        if not df_array_orig[i]['cvip'].isnull().values.any():
            df_avg_orig_cvip+=df_array_orig[i]['cvip']
            count+=1
df_avg_orig_cvip.interpolate().dropna()/count


df_avg_cvip = df_array_fric[0]['cvip']

count = 0
for i in range(1, len(df_array_fric)):
    if(df_array_fric[i]['cvip'].dtypes == 'object'):
```

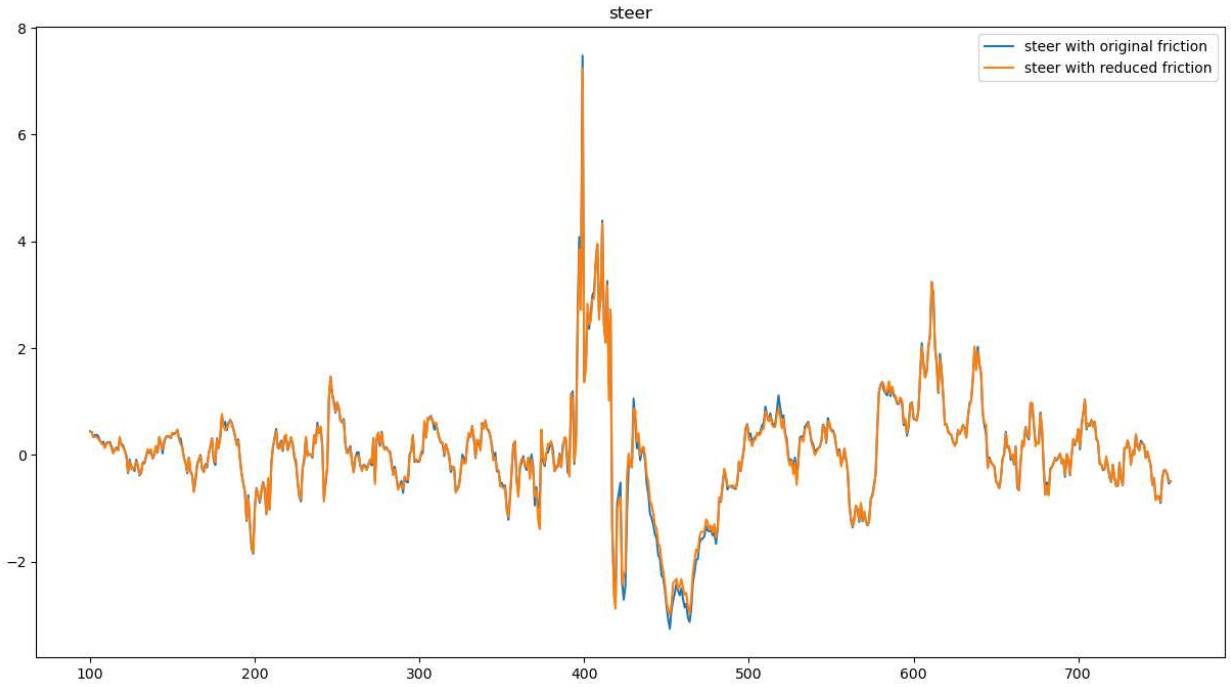
```
        print(i)
    else:
        if not df_array_fric[i]['cvip'].isnull().values.any():
            df_avg_cvip+=df_array_fric[i]['cvip']
            count+=1
df_avg_cvip.interpolate().dropna()/count

df_avg_orig_cvip.iloc[100:].plot(title="cvip")
df_avg_cvip.iloc[100:].plot(label='Reduced')

plt.legend(["cvip with original friction", "cvip with reduced friction"])
plt.show()
```



In [69]:

```
plt.figure(figsize=(15,8))

df_avg_orig_steer = df_array_orig[0]['steer']
count = 0

for i in range(1, len(df_array_orig)):
    if(df_array_orig[i]['steer'].dtypes == 'object'):
        print(i)
    else:
        if not df_array_orig[i]['steer'].isnull().values.any():
            df_avg_orig_steer+=df_array_orig[i]['steer']
            count+=1
df_avg_orig_steer.interpolate().dropna()/count


df_avg_steer = df_array_fric[0]['steer']

count = 0
for i in range(1, len(df_array_fric)):
    if(df_array_fric[i]['steer'].dtypes == 'object'):
        print(i)
    else:
        if not df_array_fric[i]['steer'].isnull().values.any():
            df_avg_steer+=df_array_fric[i]['steer']
            count+=1
```

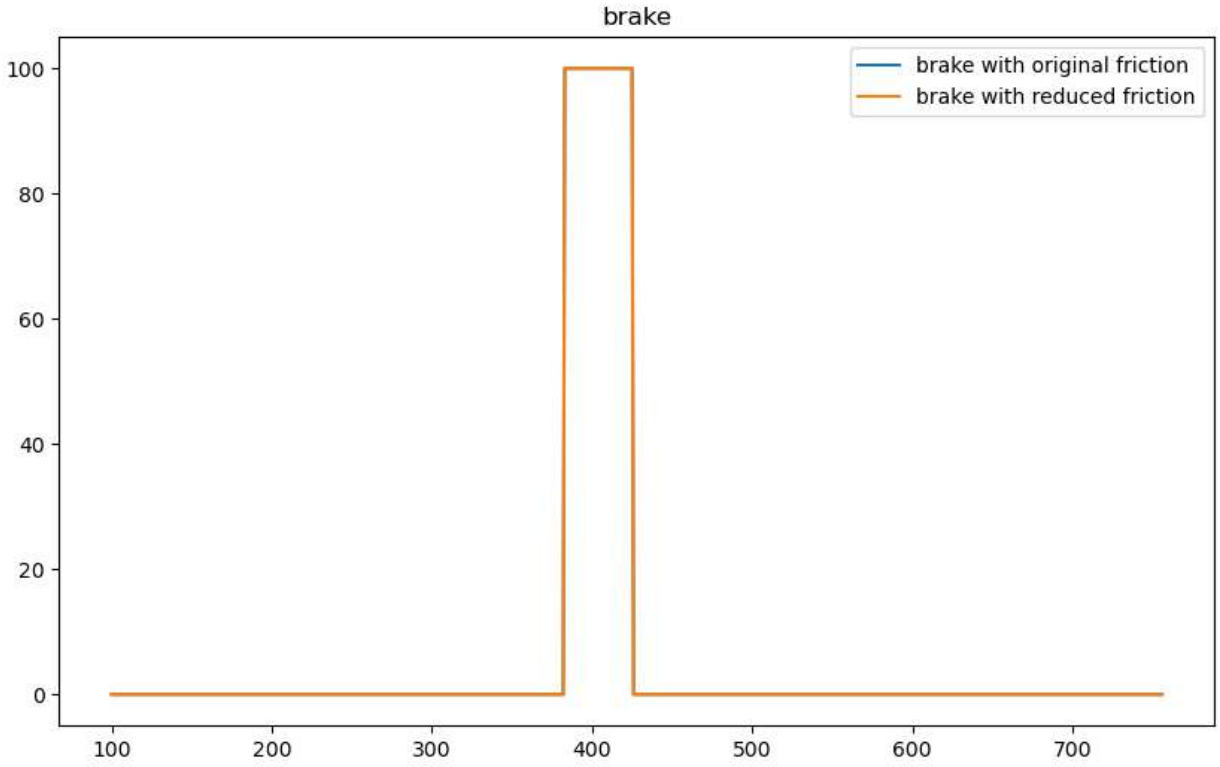
```
df_avg_steer.interpolate().dropna()/count

df_avg_orig_steer.iloc[100:].plot(title="steer")
df_avg_steer.iloc[100:].plot(label='Reduced')

plt.legend(["steer with original friction", "steer with reduced friction"])
plt.show()
```



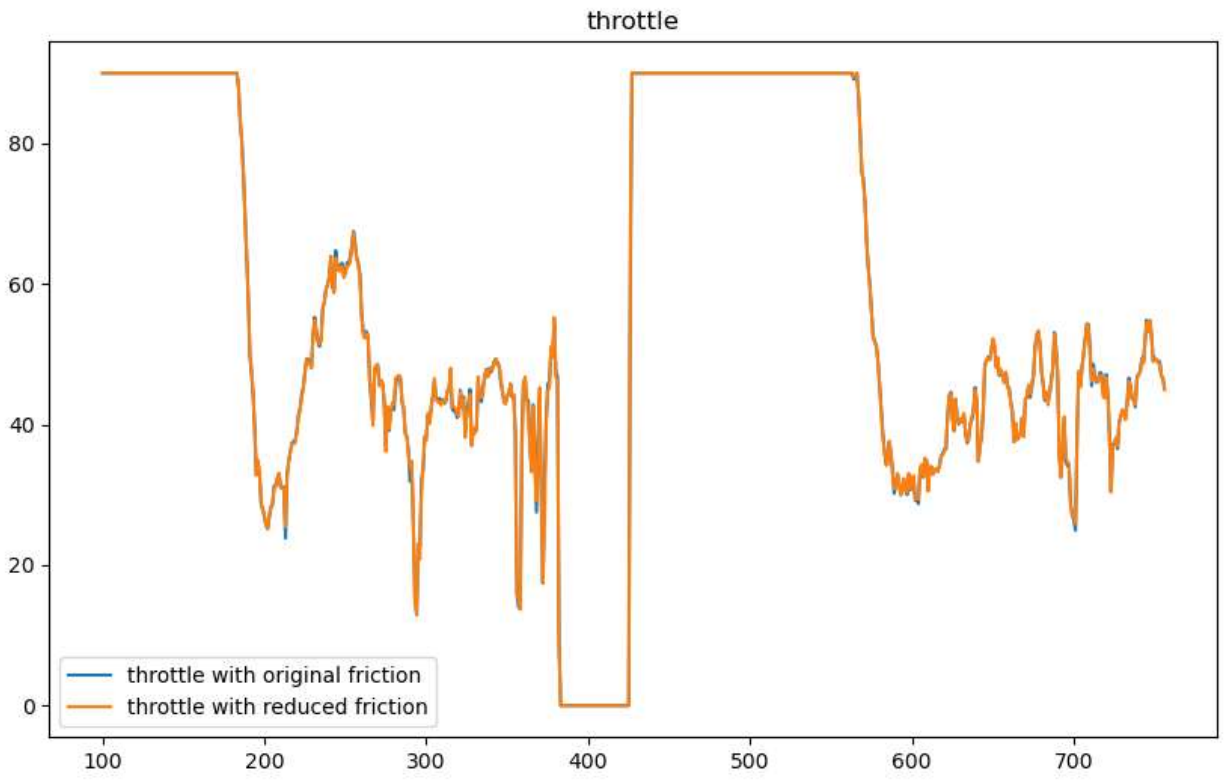
In [71]:

```
plt.figure(figsize=(10,6))

df_avg_orig_brake = df_array_orig[0]['brake']
count = 0

for i in range(1, len(df_array_orig)):
    if(df_array_orig[i]['brake'].dtypes == 'object'):
        print(i)
    else:
        if not df_array_orig[i]['brake'].isnull().values.any():
            df_avg_orig_brake+=df_array_orig[i]['brake']
            count+=1
df_avg_orig_brake.interpolate().dropna()/count


df_avg_brake = df_array_fric[0]['brake']

count = 0
for i in range(1, len(df_array_fric)):
    if(df_array_fric[i]['brake'].dtypes == 'object'):
        print(i)
    else:
        if not df_array_fric[i]['brake'].isnull().values.any():
            df_avg_brake+=df_array_fric[i]['brake']
            count+=1
df_avg_brake.interpolate().dropna()/count

df_avg_orig_brake.iloc[100:].plot(title="brake")
df_avg_brake.iloc[100:].plot(label='Reduced')
```

```
plt.legend(["brake with original friction", "brake with reduced friction"])
plt.show()
```

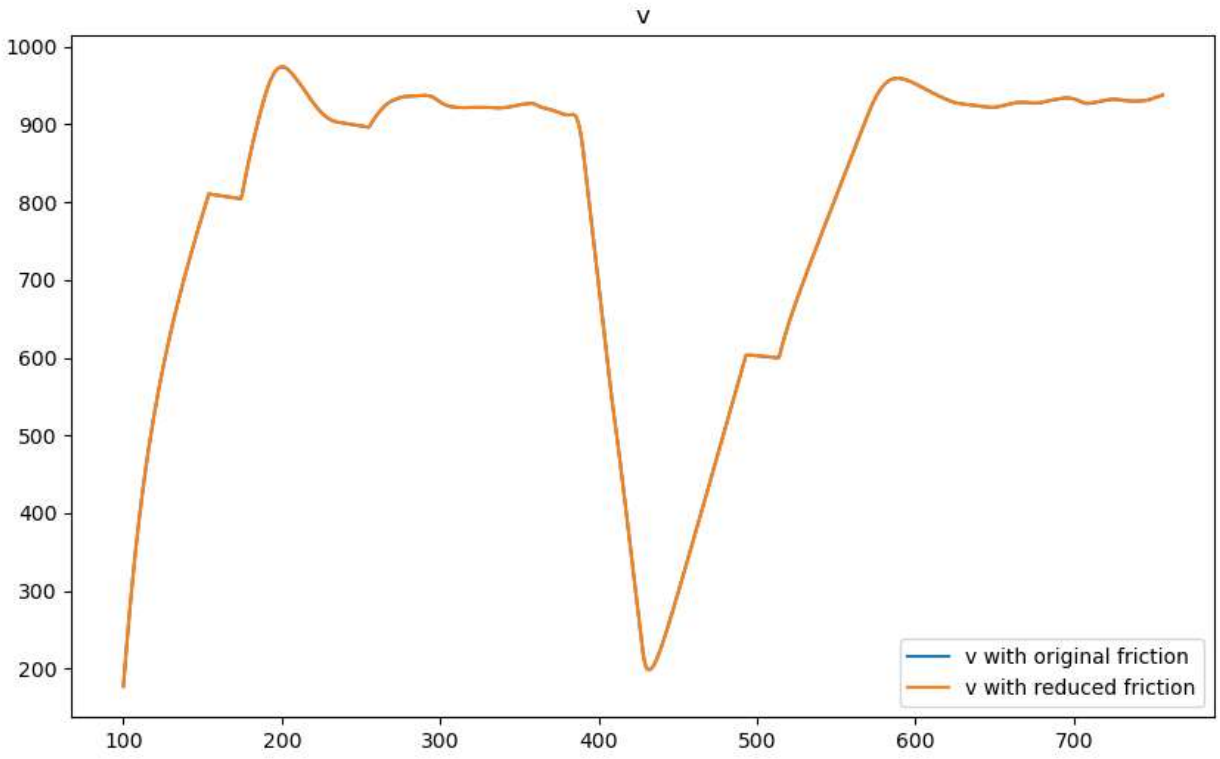


In [72]:
```
plt.figure(figsize=(10,6))

df_avg_orig_throttle = df_array_orig[0]['throttle']
count = 0

for i in range(1, len(df_array_orig)):
    if(df_array_orig[i]['throttle'].dtypes == 'object'):
        print(i)
    else:
        if not df_array_orig[i]['throttle'].isnull().values.any():
            df_avg_orig_throttle+=df_array_orig[i]['throttle']
            count+=1
df_avg_orig_throttle.interpolate().dropna()/count


df_avg_throttle = df_array_fric[0]['throttle']

count = 0
for i in range(1, len(df_array_fric)):
    if(df_array_fric[i]['throttle'].dtypes == 'object'):
        print(i)
    else:
        if not df_array_fric[i]['throttle'].isnull().values.any():
            df_avg_throttle+=df_array_fric[i]['throttle']
            count+=1
df_avg_throttle.interpolate().dropna()/count

df_avg_orig_throttle.iloc[100:].plot(title="throttle")
df_avg_throttle.iloc[100:].plot(label='Reduced')

plt.legend(["throttle with original friction", "throttle with reduced friction"])
plt.show()
```



In [73]:

```
plt.figure(figsize=(10,6))

df_avg_orig_v = df_array_orig[0]['v']
count = 0

for i in range(1, len(df_array_orig)):
    if(df_array_orig[i]['v'].dtypes == 'object'):
        print(i)
    else:
        if not df_array_orig[i]['v'].isnull().values.any():
            df_avg_orig_v+=df_array_orig[i]['v']
            count+=1
df_avg_orig_v.interpolate().dropna()/count


df_avg_v = df_array_fric[0]['v']

count = 0
for i in range(1, len(df_array_fric)):
    if(df_array_fric[i]['v'].dtypes == 'object'):
        print(i)
    else:
        if not df_array_fric[i]['v'].isnull().values.any():
            df_avg_v+=df_array_fric[i]['v']
            count+=1
df_avg_v.interpolate().dropna()/count

df_avg_orig_v.iloc[100:].plot(title="v")
df_avg_v.iloc[100:].plot(label='Reduced')

plt.legend(["v with original friction", "v with reduced friction"])
plt.show()
```



Dynamic time warping (DTW) for cvip

measuring similarity between two temporal sequences

In [75]:
```
distance = dtw.distance(median_orig_cvip, median_fric_cvip)
```

In [76]:
```
distance
```

Out[76]:
```
0.08939207349725889
```

KS Test for cvip

In [78]:
```
import scipy as sp
```

In [79]:
```
sp.stats.ks_2samp(median_orig_cvip, median_fric_cvip)
```

Out[79]:
```
KstestResult(statistic=0.005284015852047556, pvalue=1.0, statistic_location=7.995562284255972, statistic_sign=1)
```

You reject the null hypothesis that the two samples were drawn from the same distribution if the p-value is less than your significance level. **pvalue=4.2177381979173086e-06**